Particulate Matter
Air Quality Episodes
During the California Regional
$PM_{2.5}/PM_{10}$ Air Quality Study

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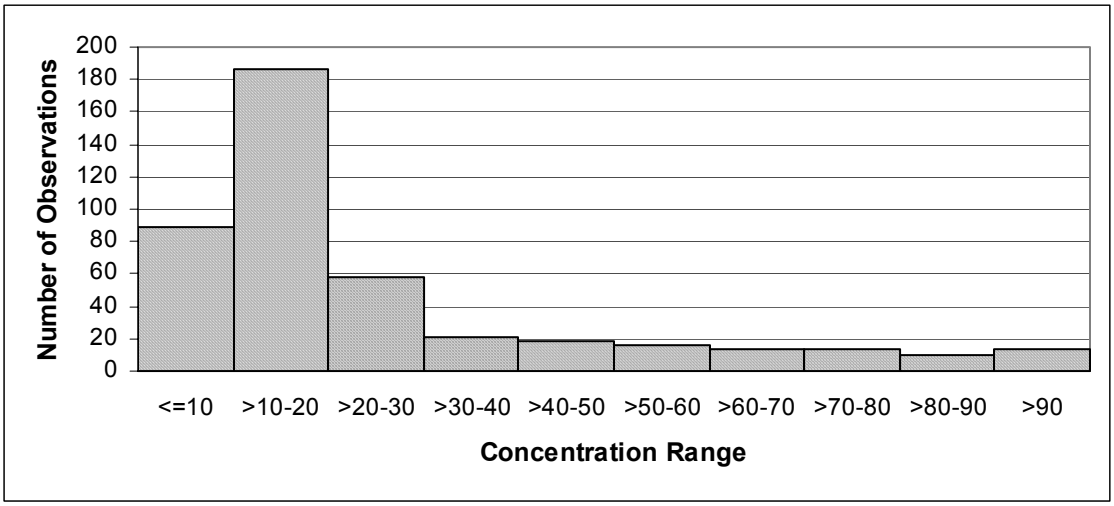
Appenix A

Particulate Matter Monitoring Sites in the San Joaquin Valley, Sacramento Valley, and San Francisco Bay Area Air Basins.

1 INTRODUCTION

Particulate matter (PM) concentrations in the San Joaquin Valley vary with the season. The concentration distribution is typically very skewed, with the majority of samples having low PM concentrations while a much smaller number have very high concentrations. The 14-month-long (December 1999-February 2001) California Regional $PM_{2.5}$/PM_{10} Air Quality Study (CRPAQS) was undertaken to better understand the causes of excessive particulate matter (PM) in central California, and to evaluate ways to reduce them. Figure 1-1 illustrates a distribution of $PM_{2.5}$ concentrations at the Bakersfield-California monitoring site during CRPAQS.

Figure 1-1 Frequency distribution of $PM_{2.5}$ concentrations at Bakersfield between 12/1/99 and 2/18/01.

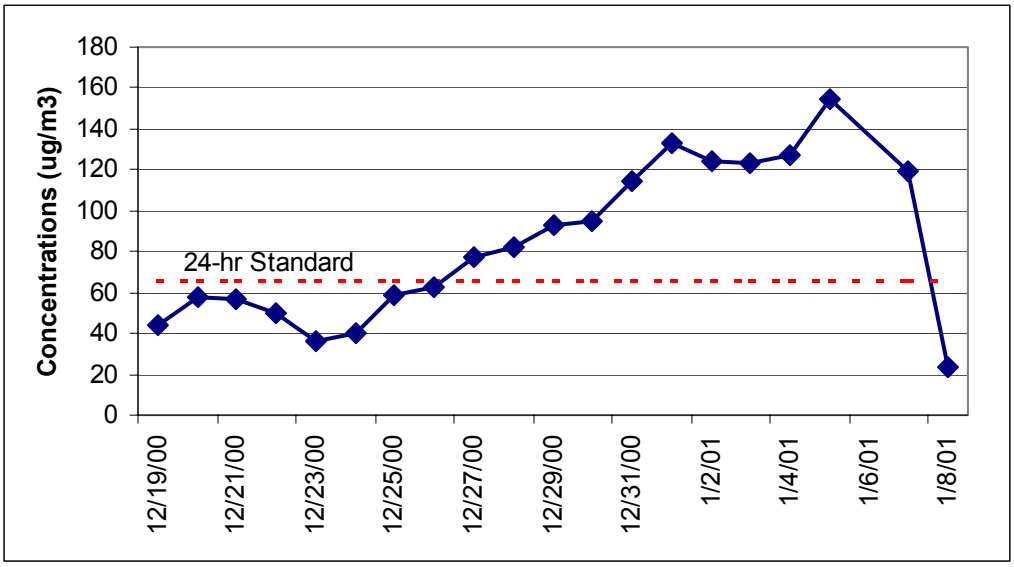


This pattern reflects the episodic nature of PM pollution. High concentrations are infrequent and usually occur when stagnant weather conditions persist in the area for many days. An episode is defined as a period of time, from the beginning of the buildup through the dissolution, during which the peak PM concentrations exceed one or both of the following standards:

1) The federal 24-hour $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) of 65 $\mu g/m^3$.
2) The federal 24-hour PM_{10} NAAQS of 150 $\mu g/m^3$.

At the beginning of the episode, concentrations are low, but increase each day due to the accumulation of primary pollutants and the formation of secondary pollutants. They continue to build up until there is a change in the weather significant enough to bring the concentrations down. Figure 1-2 illustrates the buildup in concentrations of the December 2000 Episode.

Figure 1-2 Buildup of $PM_{2.5}$ concentrations at Bakersfield between 12/19/00 and 1/8/01.



The CRPAQS captured seven air pollution episodes (Table 1-1). Each had unique characteristics, including strength and duration described in subsequent sections of this report. The two most severe episodes, December 1999 and December 2000, are described in more detail.

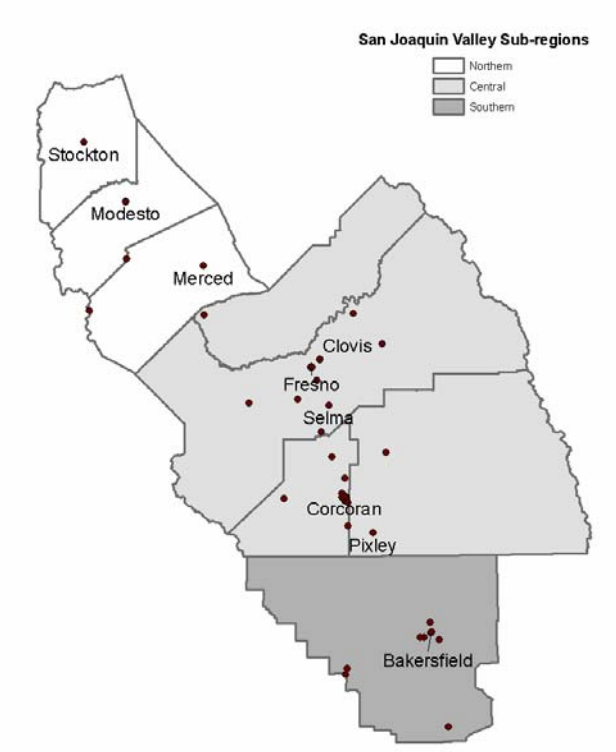
Table 1-1 Duration and strength of CRPAQS PM episodes.

Episode Name	Episode Dates	Peak Concentration ($\mu g/m^3$)		SJV Days Above 24-hour NAAQS		Peak Site	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
December 1999	12/14/99 – 1/2/00	174	129	2	18	COP	FSF
January 2000	1/2/00 – 1/12/00	147	138	0	6	VCS	FSF
November 2000	11/15/00 – 11/29/00	145	112	0	8	BGS	CLO
November/December 2000	11/30/00 – 12/13/00	127	99	0	7	VCS	FSF
December 2000	12/18/00 – 1/8/01	208	179	3	15	BGS	EDI
January 2001	1/12/01 – 1/24/01	127	120	0	7	BAC	BGS
January/February 2001	1/26/01 – 2/7/01	101	110	0	4	BGS	FSF

2 DATA COLLECTION AND ANALYSIS

The CRPAQS monitoring network was designed to complement long-term monitoring in order to improve understanding of the particulate matter problem in central California. During the CRPAQS field study, which ran from December 1999 through February 2001, the existing monitoring network was enhanced with additional monitoring sites and air quality and meteorological instruments. The focus of this analysis was on the San Joaquin Valley, which experienced the most severe particulate matter episodes, and two air basins located to the north, the San Francisco Bay Area and Sacramento Valley. Appendix A lists monitoring sites, along with site abbreviations, in the three air basins mentioned above. For the purpose of this analysis, the San Joaquin Valley was divided into three parts: northern, central, and southern (Figure 2-1). The northern part comprised San Joaquin, Stanislaus, and Merced Counties, which included the urban areas of Stockton, Modesto, and Merced. The central portion of the Valley included Madera, Fresno, Kings, and Tulare Counties. Fresno was the largest urban center in this part of the Valley and included multiple monitoring sites. The southern area included Kern County with multiple sites in the Bakersfield urban area.

Figure 2-1 Sub-regional division of the San Joaquin Valley and locations of particulate matter monitoring sites.



The air quality data analyzed in this report were collected using a wide range of samplers. The CRPAQS PM_{10} mass and chemical composition data were collected using a MiniVol sampler and the CRPAQS $PM_{2.5}$ mass and chemical composition data were collected using a MiniVol sampler or a DRI Sequential Filter Sampler (SFS). CRPAQS PM_{10} monitors operated on a one-in-six days schedule offset by three days from the routine network schedule. CRPAQS $PM_{2.5}$ monitors operated on a standard one-in-six days schedule during the annual field program, and more frequently during winter intensive episodes.

The routine PM_{10} mass data were collected using a Size Selective Inlet (SSI) sampler and the $PM_{2.5}$ data were collected using the Federal Reference Method (FRM) sampler or dichotomous (dichot) sampler. The $PM_{2.5}$ chemical composition data were collected using a Spiral Aerosol Speciation Sampler (SASS). The sampling schedule for routine monitors was adjusted seasonally and ranged from one-in-six days to every day.

Concentrations of chemical components were estimated by multiplying the measured concentration of a species by a factor representing an estimate of the unmeasured species, such as oxygen and hydrogen. For each chemical composition sample, chemical components were calculated as follows:

- Ammonium Nitrate = $1.29[NO_3^-]$
- Ammonium Sulfate = $1.38[SO_4^{2-}]$
- Organic Carbon = 1.4[OC]
- Carbonaceous aerosols = 1.4[OC] + [EC]
- Geological species = 1.89[Al] + 2.14[Si] + 1.4[Ca] + 1.43[Fe]

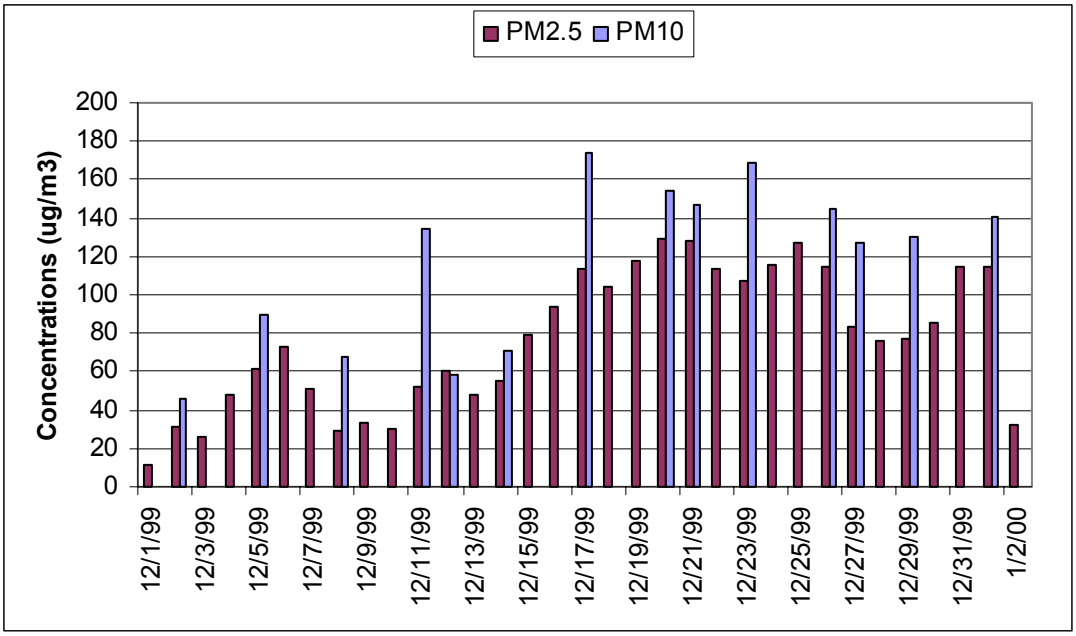
3 DECEMBER 1999 EPISODE

The December 1999 episode lasted from December 14, 1999 through January 2, 2000. The two-week period prior to this episode, from December 1 through December 13, which experienced some elevated $PM_{2.5}$ concentrations, is also briefly mentioned.

3.1 PM_{10} Concentrations

PM_{10} concentrations started increasing on December 14, 1999 and exceeded the federal 24-hour PM_{10} standard of 150 µg/m^3 for the first time on December 17 with 174 µg/m^3 measured at Corcoran-Patterson. Fresno-Drummond, the 2nd highest site with 153 µg/m^3, was also very close to the standard. (PM_{10} concentrations are rounded to the nearest 10 µg/m^3 for a comparison to the standard. Therefore, only concentrations of 155 µg/m^3 and above exceed the standard.) On December 20, three sites (Fresno-1st Street, Visalia, and Clovis) had concentrations in the low 150's, just below the level of the standard. Three days later, on December 23, two monitoring sites in the San Joaquin Valley exceeded the standard, Fresno-Drummond with 168 µg/m^3 and Hanford with 156 µg/m^3. Figure 3-1 illustrates peak PM concentrations in the San Joaquin Valley during this time period.

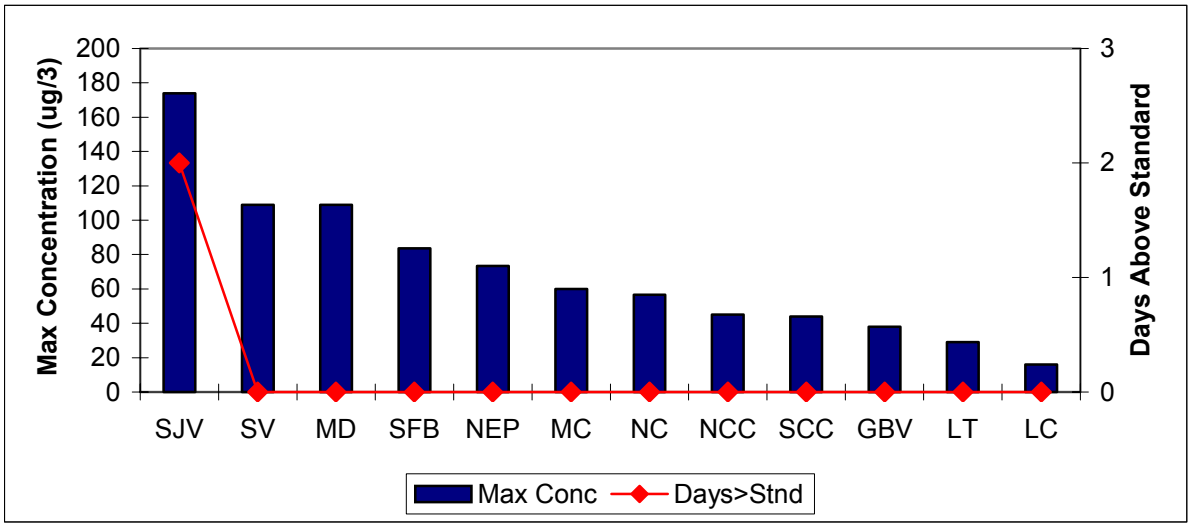
Figure 3-1 San Joaquin Valley peak PM concentrations between 12/1/99 and 1/2/00.



During this period, concentrations in northern California (North Coast, Northeast Plateau, Lake County, Lake Tahoe, and Mountain Counties Air Basins) were moderate, with a maximum concentration of 73 µg/m^3 measured at Alturas on

December 26. Concentrations in the Sacramento Valley and the San Francisco Bay Area were also moderate with maximum concentrations of 109 µg/m^3 and 84 µg/m^3, respectively. PM_{10} concentrations in the North Central Coast, South Central Coast, and Great Basin Valley Air Basins were 45 µg/m^3 and below. Mojave Desert reached a maximum PM_{10} concentration of 109 µg/m^3. Figure 3-2 illustrates maximum PM_{10} concentrations and days above the federal 24-hour PM_{10} standard in each air basin.

Figure 3-2 Maximum PM_{10} concentrations and days above federal standard between 12/14/99 and 1/2/00.



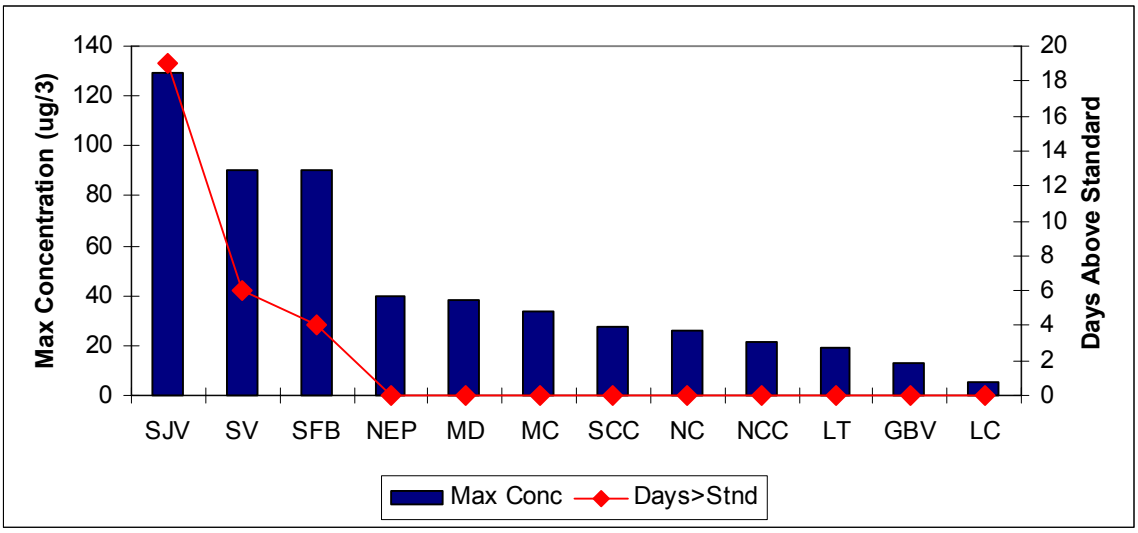
3.2 $PM_{2.5}$ Concentrations

During the first half of December, $PM_{2.5}$ concentrations peaked twice, but the peaks were only moderately high and limited to one or two days (Figure 3-1). The first peak, with 72 µg/m^3 measured at Fresno-1st on December 6, resulted in only one exceedance of the federal $PM_{2.5}$ standard of 65 µg/m^3. The second peak (not an exceedance) occurred on December 12, when concentrations at Fresno-1st reached 61 µg/m^3. Concentrations then increased steadily between December 14 and 17, and remained very high until the beginning of January. The average daily concentration for all 14 urban monitoring sites in the San Joaquin Valley exceeded the $PM_{2.5}$ standard every day from December 16 through 31. The highest concentration, 130 µg/m^3, was at Clovis on December 20. The second highest concentration, 127 µg/m^3, was measured at Fresno-1st on three separate days, December 20, 21, and 25. The average concentration measured between December 16 and January 1 was highest at Fresno-1st at 103±18 µg/m^3. Similar to PM_{10} concentrations, $PM_{2.5}$ concentrations were low in northern California (North Coast, Northeast Plateau, Lake County, Lake Tahoe, and Mountain Counties Air Basins) with a maximum concentration of 40 µg/m^3 measured on December 26 at Alturas. The Sacramento Valley Air Basin experienced a temporal pattern similar to the

San Joaquin Valley Air Basin, but with lower concentrations. On December 20, Roseville and three Sacramento sites (Sacramento-T Street, Sacramento-Del Paso Manor, and Sacramento-Health Department) measured concentrations above the standard, ranging from 79 µg/m^3 at Roseville to 90 µg/m^3 at Sacramento-T Street. Additional exceedances were measured in the Sacramento Valley on December 23, 24, and 26. During this episode, elevated concentrations reached as far north as Chico, with 73 µg/m^3 measured on December 26.

The San Francisco Bay Area Air Basin experienced elevated concentrations later than the San Joaquin Valley and Sacramento Valley Air Basins. During the course of this episode four of the Bay Area sites exceeded the standard with concentrations ranging from 67 to 91 µg/m^3. The first exceedance was captured on December 25 with 67 µg/m^3 at San Jose-Tully Road. Additional exceedances ranging from 70 to 91 µg/m^3 were measured on December 26 and 27 at Vallejo, San Francisco-Arkansas, San Jose-4th Street, and San Jose-Jackson. Figure 3-3 illustrates maximum $PM_{2.5}$ concentrations and days above the federal 24-hour $PM_{2.5}$ standard in each air basin.

Figure 3-3 Maximum $PM_{2.5}$ concentrations and days above federal standard between 12/14/99 and 1/2/00.

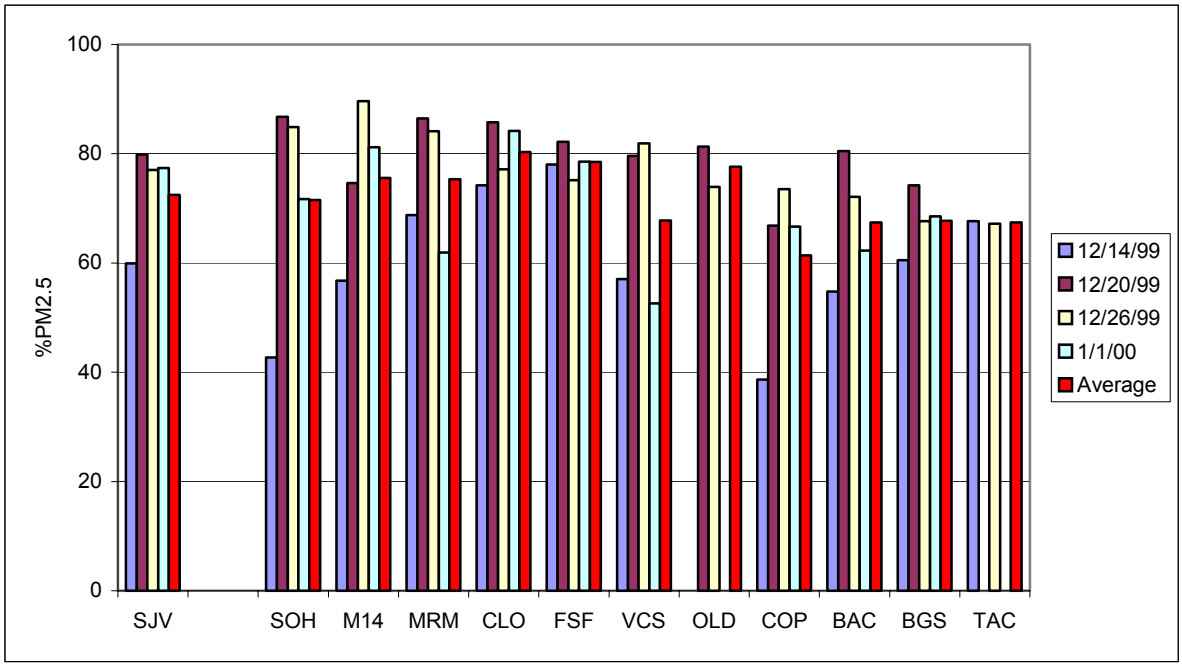


3.3 $PM_{2.5}$ to PM_{10} Ratios

The ratio of $PM_{2.5}$ to PM_{10}, indicating the fine fraction of PM, followed the same general trend shown by $PM_{2.5}$ concentrations. The episode peaked early (day 7) but was not as strong as the subsequent December 2000 episode. $PM_{2.5}$ ratios were approximately 60% at the beginning of the episode (Figure 3-4). Sites in the central portion of the Valley were generally higher, 70-80%, but some sites were as low as 40%. Stockton, a northern site, also began the episode at around 40%. In the central portion and parts of the northern Valley, the fine fraction

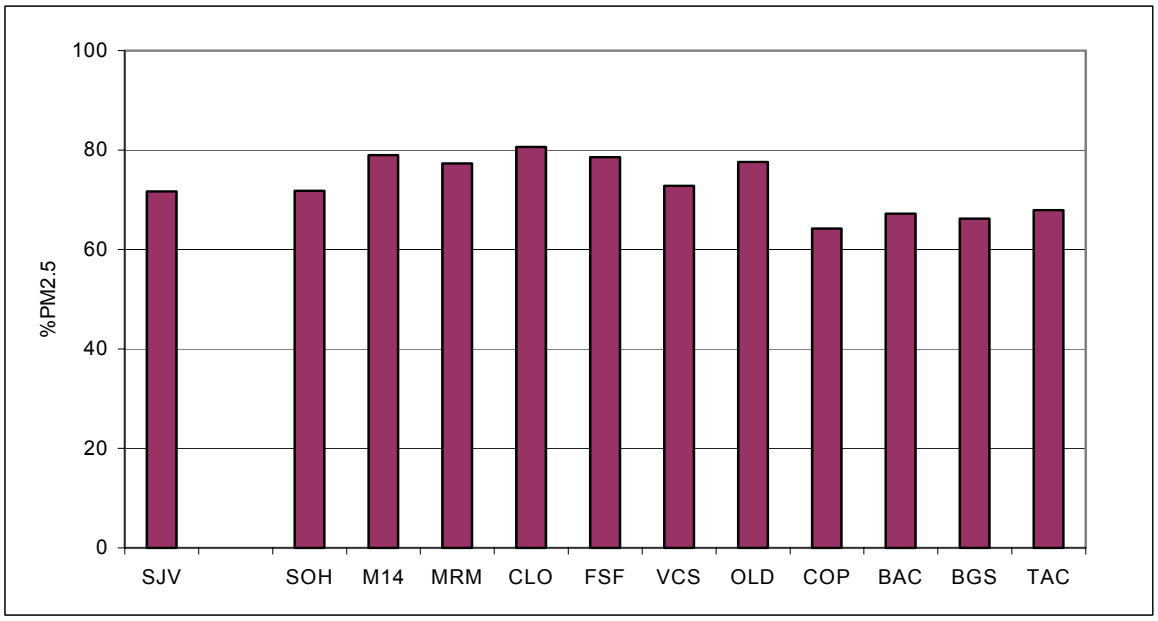
peaked on day 7, December 20th, rising to over 80%. The highest fraction, however, was reached on December 26th, when Modesto showed almost 90% of its PM being $PM_{2.5}$. By the end of the episode, January 1, 2000, ratios had decreased but were still higher than at the beginning, ranging from 50% to over 80%.

Figure 3-4 Day-to-day $PM_{2.5}/PM_{10}$ ratio at selected monitoring sites between 12/14/99 and 1/1/00.



The Valley-wide average for the episode was slightly over 70% (Figure 3-5). The majority of the selected monitoring sites were at this level, with all of them falling within a range of 60-80%. Highest average ratios were seen in the northern and central portions of the Valley.

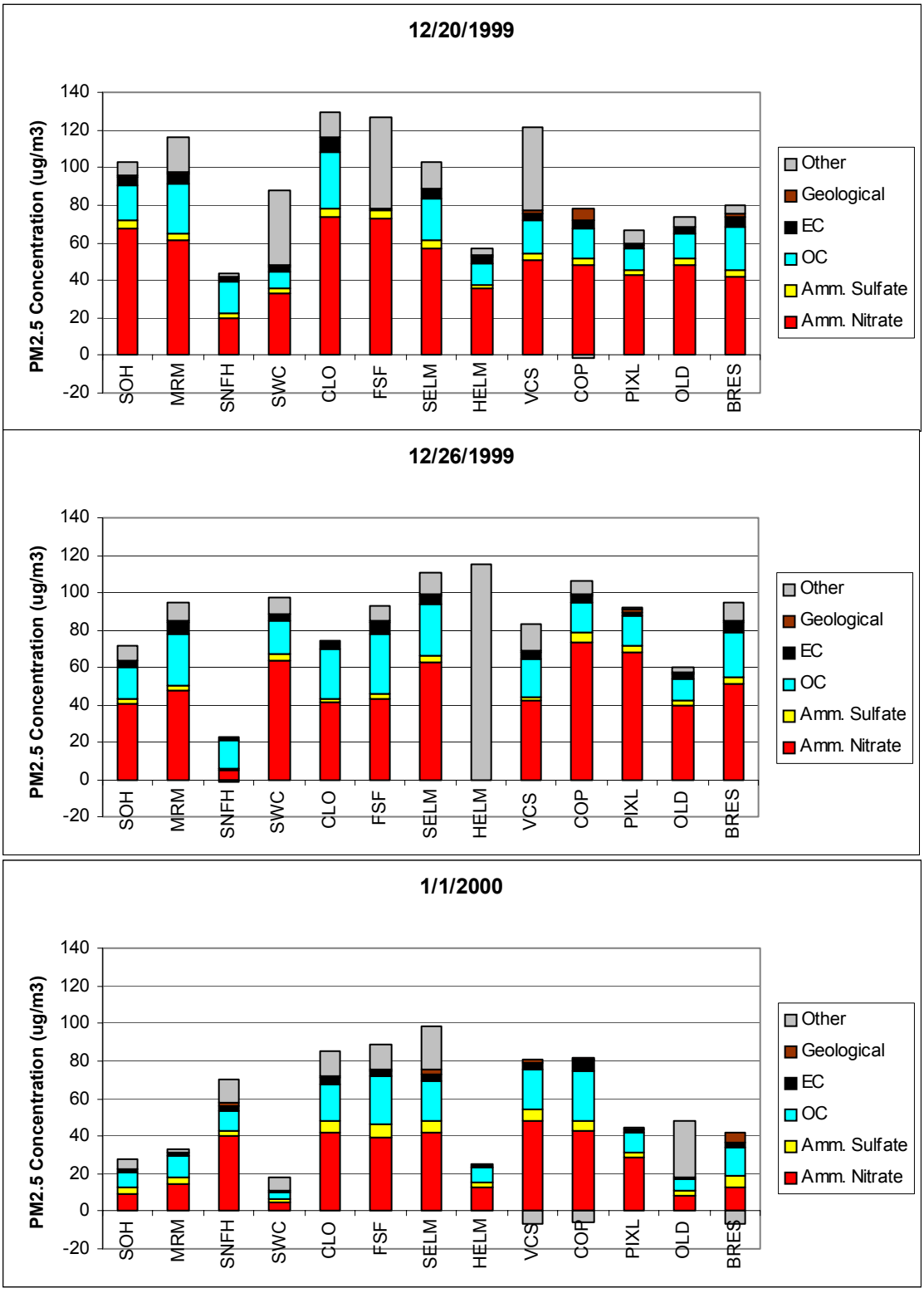
Figure 3-5 Average $PM_{2.5}/PM_{10}$ ratio at selected monitoring sites between 12/14/99 and 1/1/00.



3.4 Spatial Distribution of $PM_{2.5}$ Concentrations throughout the San Joaquin Valley

Concentrations were highest at sites along the Highway 99 corridor from Stockton in the north to Visalia and Corcoran in the south. Figure 3-6 shows $PM_{2.5}$ concentrations and chemical composition throughout the Valley on three separate sampling days. Monitoring sites in this graph are ordered based on their latitude, with the northernmost site located on the left. During the course of this episode, peak concentrations appear to gradually shift from urban to rural areas in the southerly direction. The weather started to change on December 30, with a trough moving through bringing cooler temperatures and light precipitation, and $PM_{2.5}$ concentrations dropped in both the northern and southern Valley. By January 2 these changes reached the central Valley, resulting in a similar drop in concentrations. While the episode was winding down throughout the Valley, easterly winds and greater mixing heights allowed transport of pollutants to the more remote location of the Sierra Nevada Foothills monitoring site located 500 meters above Mean Sea Level, resulting in $PM_{2.5}$ concentrations of 70 $\mu g/m^3$ on January 1. During this episode the pollution buildup affected the entire Valley, but the concentrations were highest in the Fresno area.

Figure 3-6 Spatial distribution of $PM_{2.5}$ chemical components throughout the San Joaquin Valley between 12/20/99 and 1/1/00.

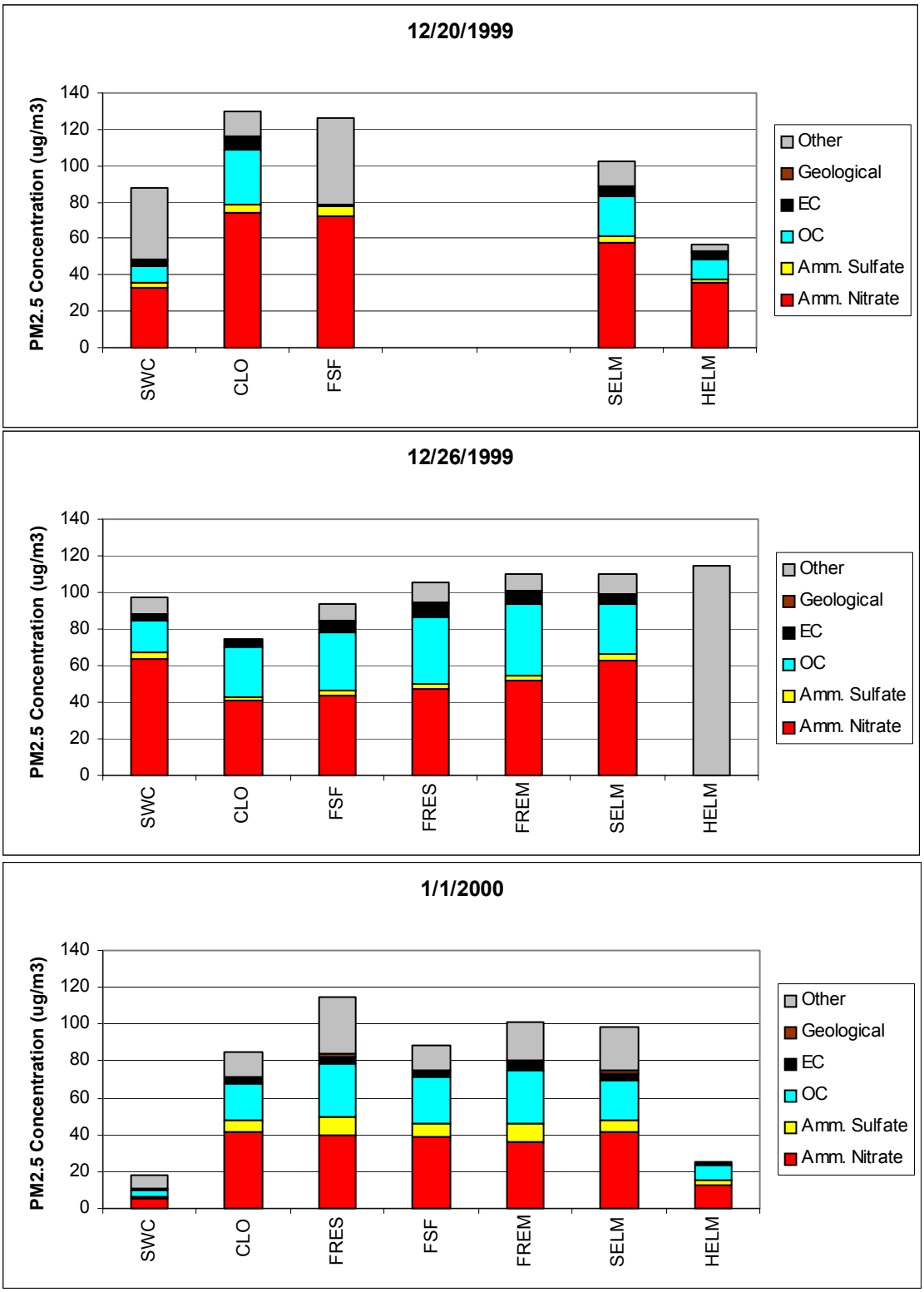


3.5 Spatial Distribution of $PM_{2.5}$ Concentrations around Fresno Area

At the beginning of the episode, Clovis and Fresno-1st had the highest $PM_{2.5}$ concentrations in the Fresno area. While on December 20, 1999, the $PM_{2.5}$ concentrations at urban sites like Clovis and Fresno were above 120 $\mu g/m^3$, surrounding rural sites such as Selma and Helm were 30 to 70 $\mu g/m^3$ lower. Six days later, on December 26, 1999, concentrations at many rural sites exceeded the urban sites, with a maximum of 115 $\mu g/m^3$ measured southwest of Fresno at Helm.

By January 1, 2000, while $PM_{2.5}$ concentrations to the north and west of Fresno had dropped to about 20 $\mu g/m^3$, concentrations remained high (up to 115 $\mu g/m^3$) at sites in and south of Fresno. Ammonium nitrate concentrations were fairly constant from Clovis in the north to Selma in the south. Figure 3-7 shows the spatial distribution of $PM_{2.5}$ concentrations and their chemical components in the Fresno area.

Figure 3-7 Spatial distribution of $PM_{2.5}$ chemical components around the Fresno area between 12/20/99 and 1/1/00.



3.6 Comparison of Daily $PM_{2.5}$ Data from Fresno and Bakersfield

Daily $PM_{2.5}$ data collected at Bakersfield-California and Fresno-1st Street show significant differences between the two sites in pollutant severity (Figure 3-8 and Figure 3-9). Fresno-1st not only had more days with unhealthy $PM_{2.5}$ levels, but the margin by which the federal standard was exceeded was also much higher. While Fresno-1st exceeded the federal $PM_{2.5}$ standard on 18 consecutive days between December 15, 1999 and January 1, 2000, Bakersfield had only 11 exceedances. Concentrations at Fresno exceeded 100 $\mu g/m^3$ on nine days as compared to one day at Bakersfield, and the average concentration across the episode was about 30 $\mu g/m^3$ higher at Fresno (103 ± 18 $\mu g/m^3$ compared to 74 ± 19 $\mu g/m^3$). Both sites measured some of the highest concentrations around the holidays, December 24 and 25, and again on December 31. This effect however was most pronounced at Fresno-1st.

Figure 3-8 PM concentrations at Fresno-1st between 12/1/99 and 1/2/00.

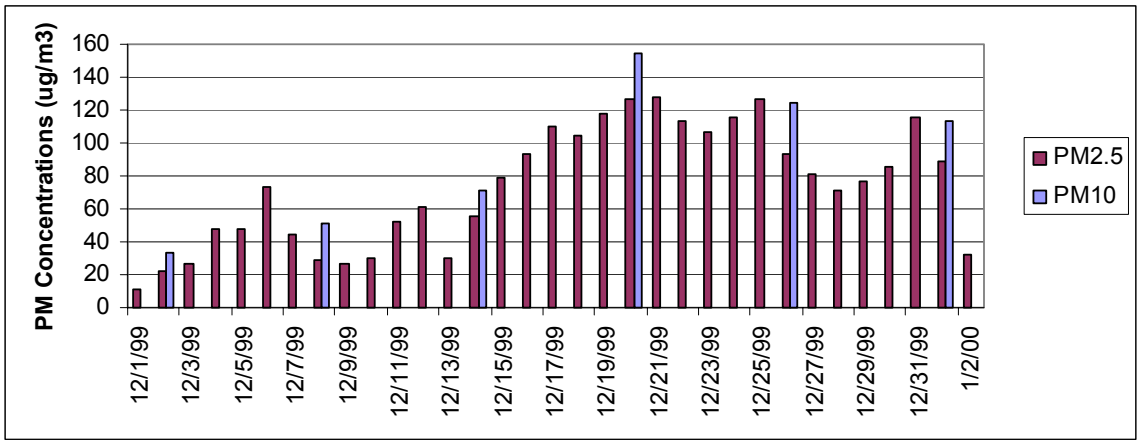
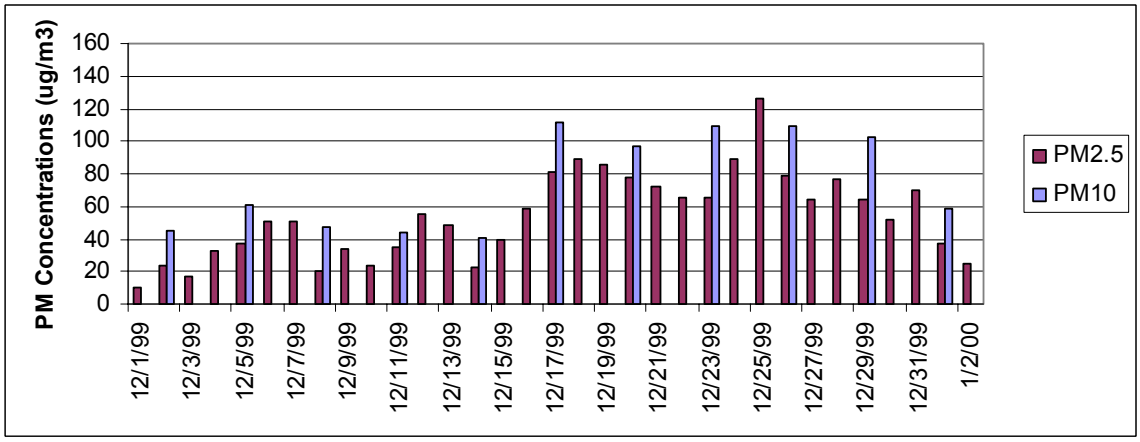


Figure 3-9 PM concentrations at Bakersfield-California between 12/1/99 and 1/2/00.



3.7 $PM_{2.5}$ Chemical Composition

Ammonium nitrate was the dominant component of $PM_{2.5}$ mass during the December 1999 episode. In the San Joaquin Valley, the average contribution from ammonium nitrate was about 60% on December 20 and 26, dropping to about 40% by January 1. Site-to-site variations were fairly significant at the beginning of the episode, but by January 1 uniform concentrations of 40 $\mu g/m^3$ of ammonium nitrate were found at all sites in the central Valley. Organic carbon was the second highest component of the $PM_{2.5}$ mass ranging from an average of 22% on December 20 to 28% on December 26.

3.7.1 Ammonium Nitrate

Ammonium nitrate concentrations varied from day to day and site to site. The magnitude of concentrations and temporal patterns depended on the following factors:

1. Location with respect to primary emission sources (rural vs. urban).
2. Geographic region (latitude).

Urban sites experience a more rapid buildup in concentrations compared to rural sites due to the proximity of emission sources. As illustrated in Figure 3-10, both urban and rural sites reached similar concentrations, but at different times. While most urban sites with local emission sources reached their peak concentrations on December 20 (Figure 3-11), concentrations at rural sites located away from primary sources continued to increase until December 26 (Figure 3-12). This delay likely reflects an impact of transport on rural sites.

The area most impacted by this episode extended from Clovis in the north to Corcoran in the south. Figure 3-13 illustrates the relationship between urban concentrations represented by Clovis and Fresno and more rural concentrations represented by Selma and Corcoran. The two rural sites were south of Fresno and Clovis. On December 20, concentrations of ammonium nitrate were higher at the urban sites. However, over the next few days while concentrations decreased at urban sites, rural sites experienced a steady increase. By December 26, rural sites had higher concentrations of ammonium nitrate than the urban sites. At the end of the episode, on January 1, 2000, urban and rural sites had fairly uniform concentrations of about 40 $\mu g/m^3$. When comparing rural sites alone (Figure 3-12), it appears that they followed the same spatial pattern as the urban sites with concentrations increasing from north to south throughout the episode.

The Sacramento Valley sites had a temporal trend similar to the urban sites in the San Joaquin Valley, with the peak ammonium nitrate concentration on December 20. Sites in the San Francisco Bay Area however, did not peak until December 26, similar to rural sites in the San Joaquin Valley.

Figure 3-10 Maximum 24-hour $PM_{2.5}$ ammonium nitrate concentrations on 12/20/99 and 12/26/99.

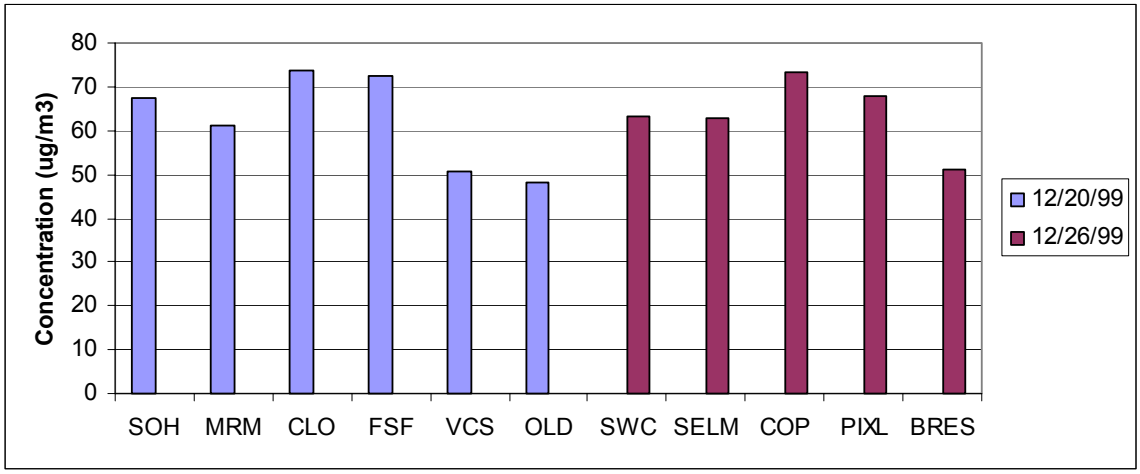


Figure 3-11 Urban $PM_{2.5}$ ammonium nitrate concentrations between 12/14/99 and 1/1/00.

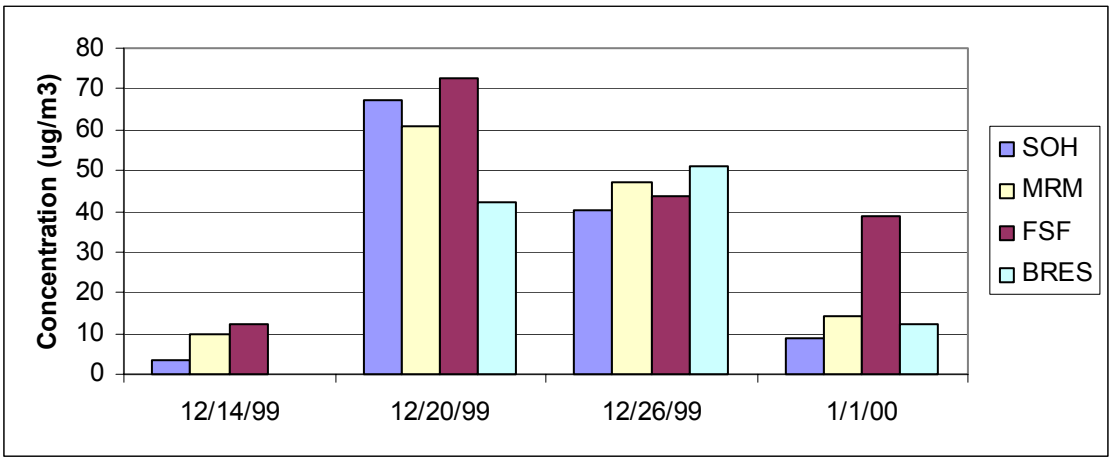


Figure 3-12 Rural $PM_{2.5}$ ammonium nitrate concentrations between 12/14/99 and 1/1/00.

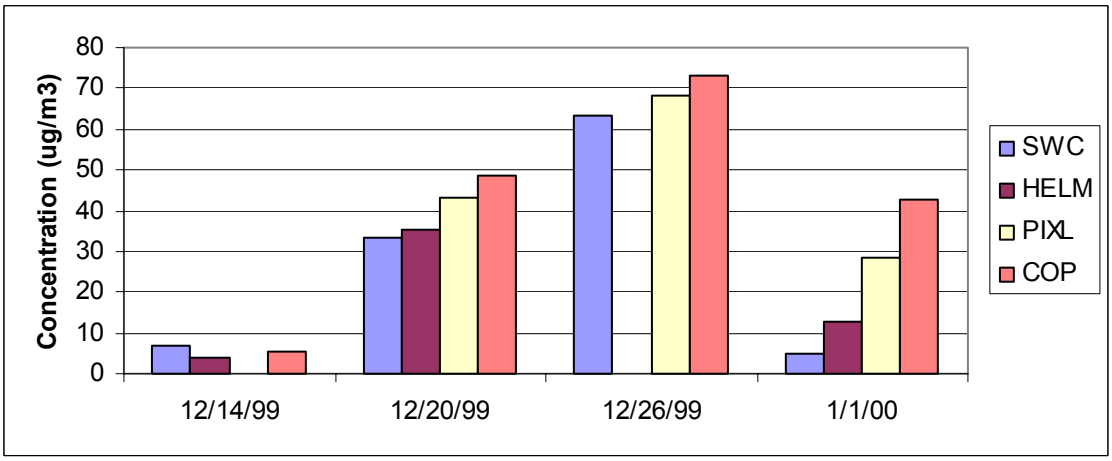
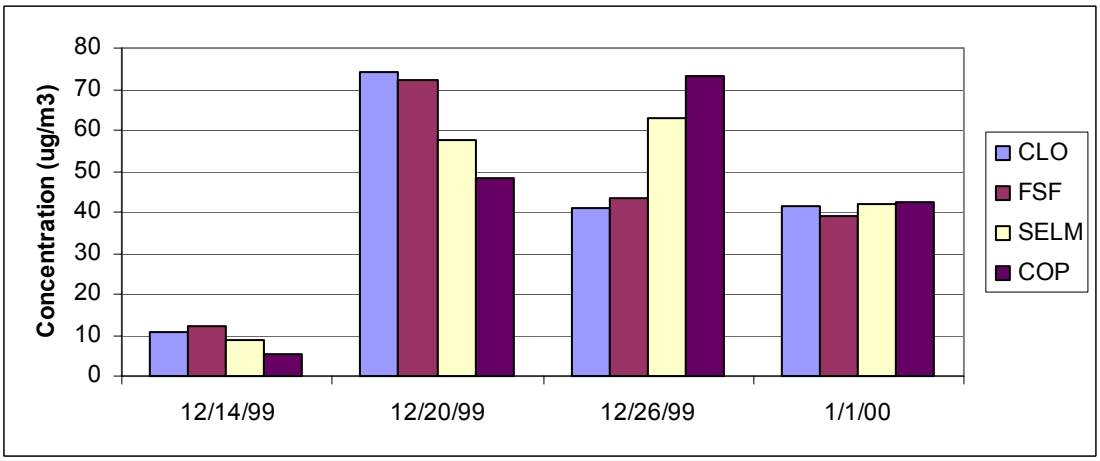


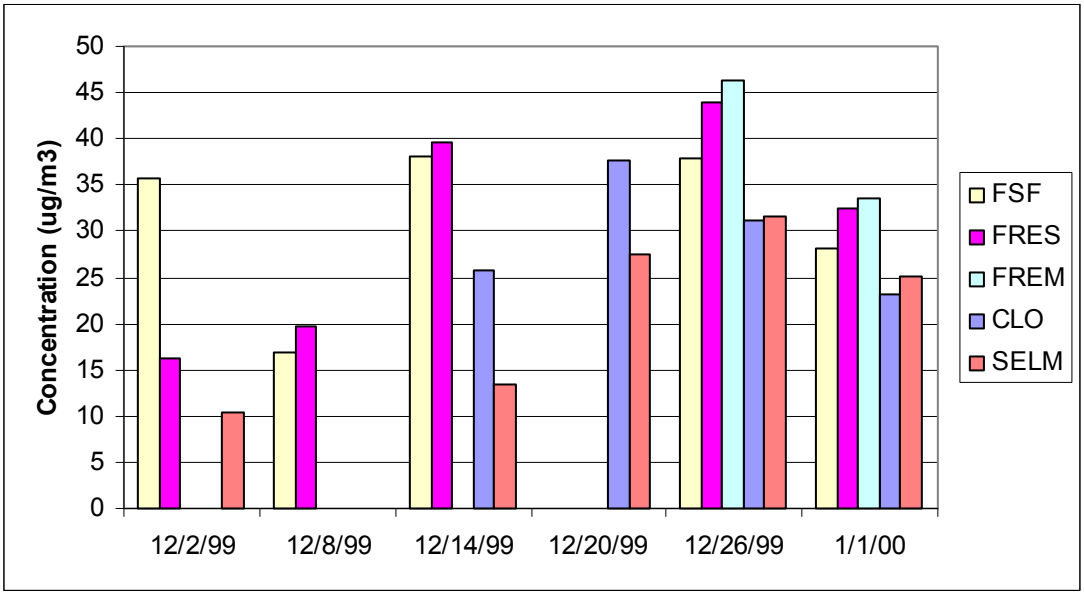
Figure 3-13 Fresno Area $PM_{2.5}$ ammonium nitrate concentrations between 12/14/99 and 1/1/00.



3.7.2 Carbonaceous aerosols

Elevated concentrations of carbonaceous aerosols were first measured on December 14. The areas most affected by the high concentrations were the same areas that six days later experienced high ammonium nitrate concentrations, sites in the northern and central San Joaquin Valley. Between December 14 and January 1, carbonaceous aerosols concentrations showed some day-to-day variations, but not as much as ammonium nitrate. Carbonaceous aerosols concentrations on January 1, 2000, New Year's Day, were surprisingly lower than on December 26, 1999, the previous sampling day. This suggests that changes in atmospheric mixing and dispersion had a greater influence on ambient concentrations than the expected increase in carbon emissions, which are often higher on New Year's Day due to holiday woodburning. The highest concentrations, up to 46 $\mu g/m^3$, were found in the Fresno area, but even there the site-to-site variations were significant, as illustrated in Figure 3-14. Urban sites outside of the Fresno area had concentrations ranging from 14 $\mu g/m^3$ at Oildale to 34 $\mu g/m^3$ at Merced.

Figure 3-14 $PM_{2.5}$ carbonaceous aerosols concentrations between 12/1/99 and 1/1/00.



Carbonaceous aerosols concentrations, like ammonium nitrate, had a different temporal pattern at rural sites than at urban. At rural sites carbonaceous aerosols concentrations followed ammonium nitrate, peaking on December 26 (Figure 3-15). At urban sites, on the other hand, they peaked a few days earlier than ammonium nitrate and showed less day-to-day variations (Figure 3-16). Both elemental and organic carbon followed the same pattern with organic carbon concentrations three to six times higher than elemental carbon.

While ammonium nitrate concentrations were similar at urban and rural sites, carbonaceous aerosols concentrations were higher at the urban sites. Comparison of two urban sites, Merced and Clovis, and a rural site located between them, Southwest Chowchilla, shows that peak ammonium nitrate concentrations at Southwest Chowchilla were close to urban peaks (higher than Merced by 4% and only 14% lower than Clovis) (Figure 3-17). Carbonaceous aerosols concentrations, on the other hand, were 40% lower at Southwest Chowchilla compared to the two urban sites. This difference in spatial distribution between ammonium nitrate and carbon was related to their origin and formation. Ammonium nitrate is considered a secondary pollutant (formed from directly emitted gasses reacting in the atmosphere). Most of the carbon, on the other hand, is considered a primary pollutant (directly emitted into the atmosphere as a particle). The fairly uniform ammonium nitrate concentrations throughout the San Joaquin Valley reflects more regional secondary formation and mixing mechanisms. In contrast, carbonaceous aerosols concentrations were greater at urban sites than rural due to the greater number of primary emission sources.

Figure 3-15 Rural $PM_{2.5}$ ammonium nitrate and carbonaceous aerosols concentrations at Southwest Chowchilla between 12/8/99 and 1/1/00.

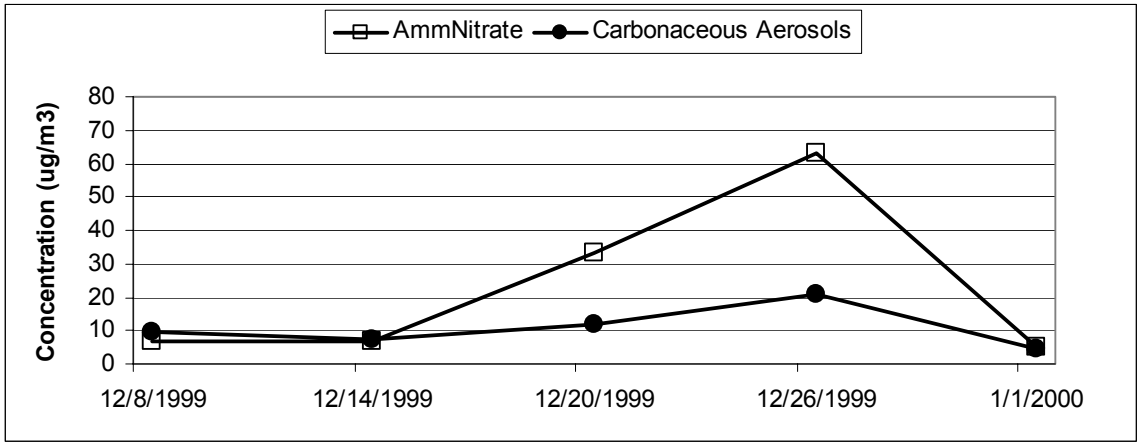


Figure 3-16 Urban $PM_{2.5}$ ammonium nitrate and carbonaceous aerosols concentrations at Stockton-Hazelton between 12/8/99 and 1/1/00.

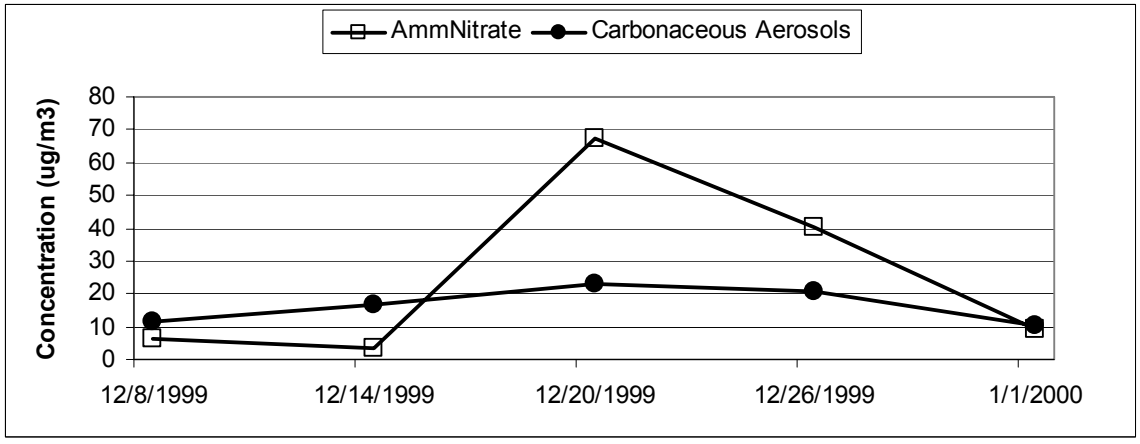


Figure 3-17 $PM_{2.5}$ ammonium nitrate concentrations between 12/14/99 and 1/1/00.

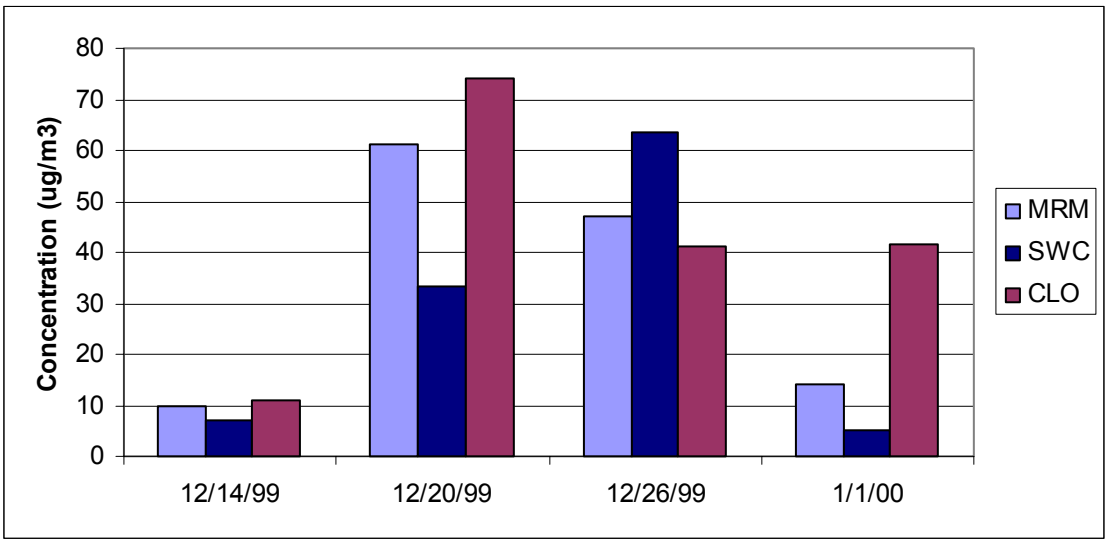
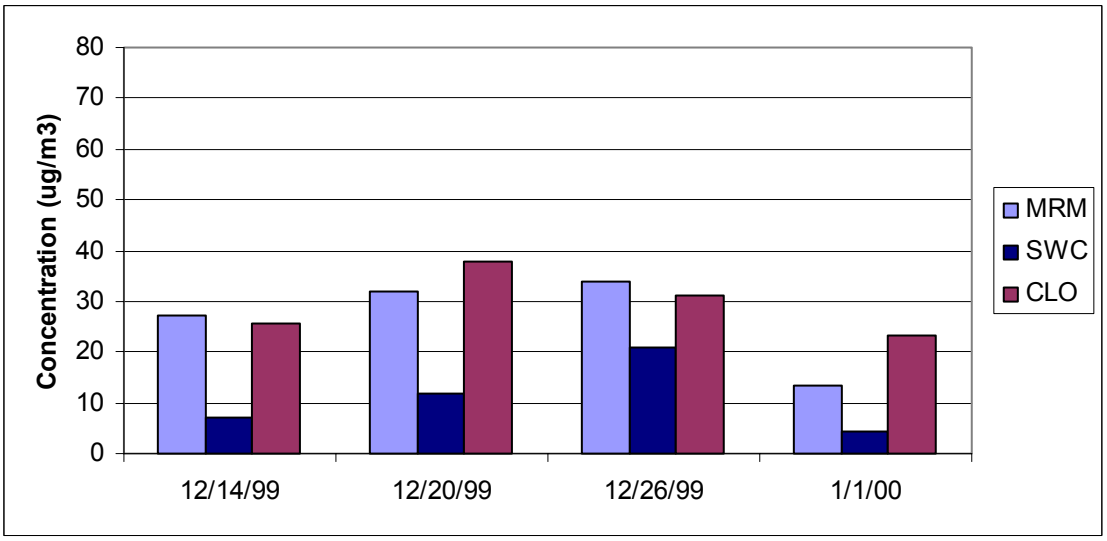


Figure 3-18 $PM_{2.5}$ carbonaceous aerosols concentrations between 12/14/99 and 1/1/00.

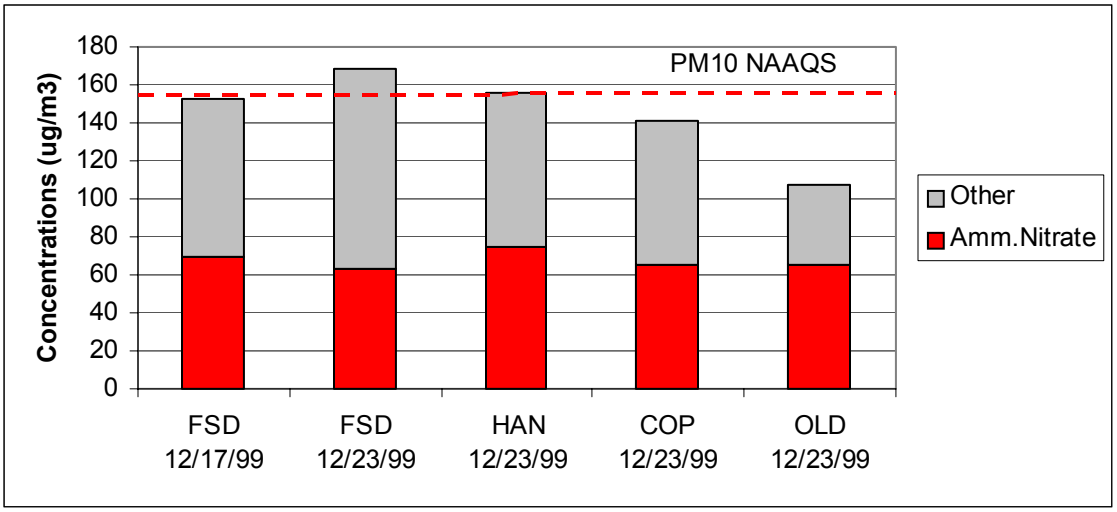


3.8 PM_{10} Chemical Composition

Since the collection of PM_{10} chemical composition data was offset by three days from the regular sampling schedule, the data were collected on December 23 and 29. These data helped to fill in gaps in the $PM_{2.5}$ data set. Between December 20 and 23, ammonium nitrate concentration decreased at Fresno sites and increased at sites to the south (Corcoran, Oildale, and Bakersfield). This further illustrates the southerly progression of the episode.

The average PM_{10} sample composition collected during this episode had about 45% ammonium nitrate and sulfate, with the remaining mass almost equally split between geological material and carbonaceous aerosols. These latter two played an important role in pushing PM_{10} concentrations over the federal standard, as illustrated in Figure 3-19. Monitoring sites with similar nitrate concentrations had significant variations in PM_{10} total mass due to the variations in carbon and geological material.

Figure 3-19 Ammonium nitrate as a fraction of PM_{10} mass during December 1999 episode.



3.9 Summary

While the entire period of December 1999 through January 1, 2000 can be considered one episode, the highest concentrations occurred between December 15 and January 1, when both the federal PM_{10} and $PM_{2.5}$ standards were exceeded. The PM_{10} standard was only exceeded in the San Joaquin Valley on two days and by only a narrow margin. However, the $PM_{2.5}$ exceedances were widespread, prolonged, and of high magnitude. $PM_{2.5}$ exceedances were measured not only in the San Joaquin Valley, but also in the Sacramento Valley and the San Francisco Bay Area. The pollution, however, was most severe in the San Joaquin Valley, with Fresno-1st exceeding the $PM_{2.5}$ standard every day between December 15 and January 1. Some of the highest concentrations were twice the level of the federal $PM_{2.5}$ standard.

Ammonium nitrate was the dominant component of the PM mass. While ammonium nitrate alone was sufficiently high to exceed the $PM_{2.5}$ standard at a few sites, elevated concentrations of carbon and geological material were needed to push the PM_{10} concentrations over the standard.

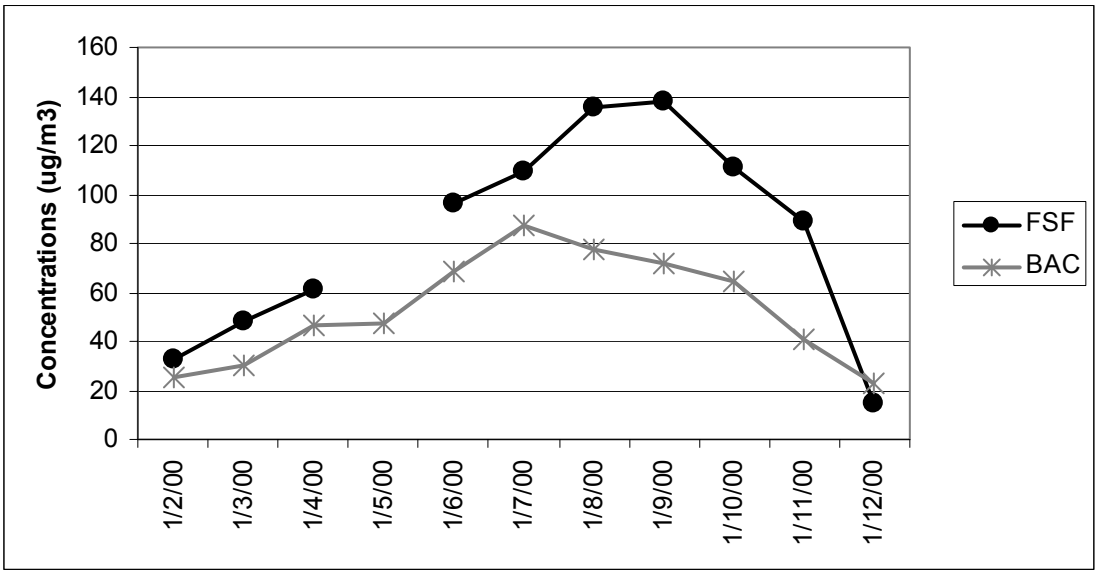
The area most affected by this episode stretched from Stockton in the north to Corcoran in the south. It appears that the long duration of the episode and the

buildup and spread of pollutants from urban to rural areas in the southerly direction was primarily responsible for widespread exceedances. This is illustrated by a delayed peak in ammonium nitrate and organic carbon concentrations at rural sites as well as a spatial (north to south) gradient in concentrations.

4 JANUARY 2000 EPISODE

The January 2000 episode lasted from January 2 through 12, 2000. During this period the Fresno area had the highest $PM_{2.5}$ concentrations, reaching close to 140 µg/m^3 on January 8 and 9. The Fresno-1st Street monitoring site had six days with concentrations above the federal $PM_{2.5}$ standard. Concentrations at Bakersfield were significantly lower and exceeded the standard on only four days. Figure 4-1 illustrates $PM_{2.5}$ concentrations at both sites. PM_{10} concentrations remained below the standard throughout the episode. Even though this episode was short in duration, lasting only ten days, there was still enough time for emissions to spread throughout the area, resulting in $PM_{2.5}$ exceedances at rural sites such as Southwest Chowchilla, Selma, Kettleman City, Corcoran, Angiola, and Pixley. Rural sites in the central San Joaquin Valley had the highest concentrations, with almost 120 µg/m^3 measured at Kettleman City. On January 8, $PM_{2.5}$ concentrations exceeded the standard as far north as Stockton, and by January 9 the standard was exceeded at Sacramento-13th Street, a monitoring site in the southern portion of the Sacramento Valley.

Figure 4-1 $PM_{2.5}$ concentrations between 1/2/00 and 1/12/00.



The dynamics of this episode were very interesting. It was preceded by a very strong and prolonged episode in December of 1999, which ended with light precipitation on January 1 or 2. While monitoring sites in the northern and

southern San Joaquin Valley experienced concentrations below the standard on January 1, it took another day for the Fresno area to see a similar drop. After a brief period of low $PM_{2.5}$ levels, concentrations climbed steadily and again exceeded the standard on January 6. The $PM_{2.5}$ chemical composition data were collected on January 7, before $PM_{2.5}$ concentrations in the central San Joaquin Valley reached their peak on January 8 or 9. On the 7th, as shown in Figure 4-2, the spatial distribution of chemical components was typical for a winter episode; $PM_{2.5}$ concentrations in the Fresno area were dominated by carbon while in the rest of the Valley they were dominated by ammonium nitrate. However, as the PM_{10} chemical composition data in Figure 4-3 shows, by the end of the episode ammonium nitrate concentrations exceeded the organic and elemental carbon even in the Fresno area.

Figure 4-2 Spatial distribution of $PM_{2.5}$ chemical components on 1/7/00.

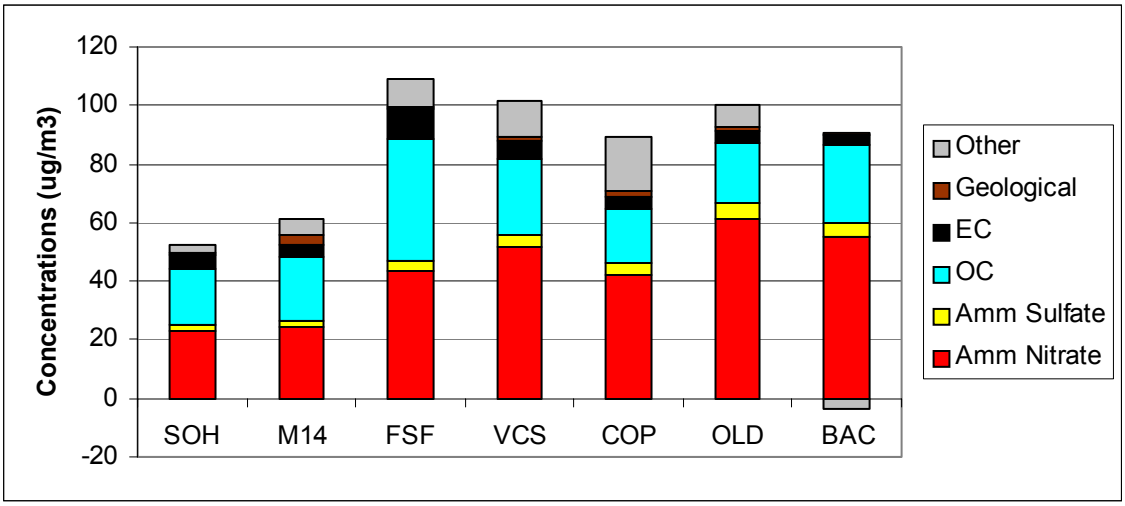
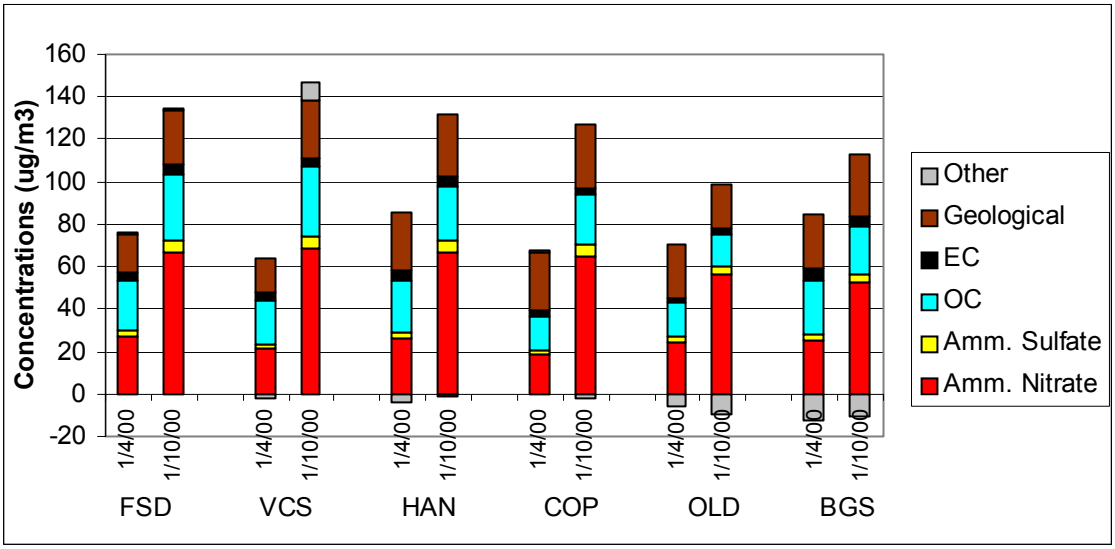


Figure 4-3 Temporal changes in PM_{10} chemical components between 1/4/00 and 1/10/00.



5 NOVEMBER 2000 EPISODE

The November 2000 episode lasted from November 15 through 29, 2000. It had two fairly distinct peaks: the first one around November 20 or 21 (followed by a brief decline in concentrations on November 22), and the second one on November 24 or 25. Both peaks occurred during Thanksgiving week, the first on the Monday or Tuesday before Thanksgiving, and the second on the Friday or Saturday after Thanksgiving. During the first peak, 14 monitoring sites from Stockton in the north to Edison in the south exceeded the federal 24-hour $PM_{2.5}$ standard with concentrations ranging from 66 $\mu g/m^3$ at Stockton to 112 $\mu g/m^3$ at Clovis. One Sacramento Valley site, Chico-Manzanita, also had concentrations above the standard. During the second peak, $PM_{2.5}$ concentrations were lower (below 78 $\mu g/m^3$) throughout the Valley, but especially in the central and southern San Joaquin Valley, with almost all exceedances occurring in the Bakersfield area. Carbonaceous aerosols played a significant role in pushing concentrations over the standard. For example, during the first peak, the Fresno-1st Street site had more than 50 $\mu g/m^3$ of carbonaceous aerosols. While both peaks had similar ammonium nitrate concentrations, lower concentrations of carbonaceous aerosols during the second peak resulted in lower $PM_{2.5}$ mass.

Bakersfield and Fresno had similar temporal patterns, with peaks at Fresno occurring one day earlier than those at Bakersfield (Figure 5-1). However, with more days above the standard (five days at Bakersfield versus three at Fresno) and higher peaks (96 $\mu g/m^3$ at Bakersfield versus 87 $\mu g/m^3$ at Fresno), the episode was stronger at Bakersfield.
Figure 5-2 compares $PM_{2.5}$ chemical composition at selected sites on November 20 and November 26.

Rural sites had moderately high $PM_{2.5}$ concentrations with only two sites, Kettleman City and Fellows, exceeding the standard. It is interesting to note that both Fellows and the Foothills site above Fellows had relatively high concentrations during the first peak and during the second peak showed concentrations similar to Bakersfield.

Figure 5-1 $PM_{2.5}$ concentrations between 11/15/00 and 11/29/00.

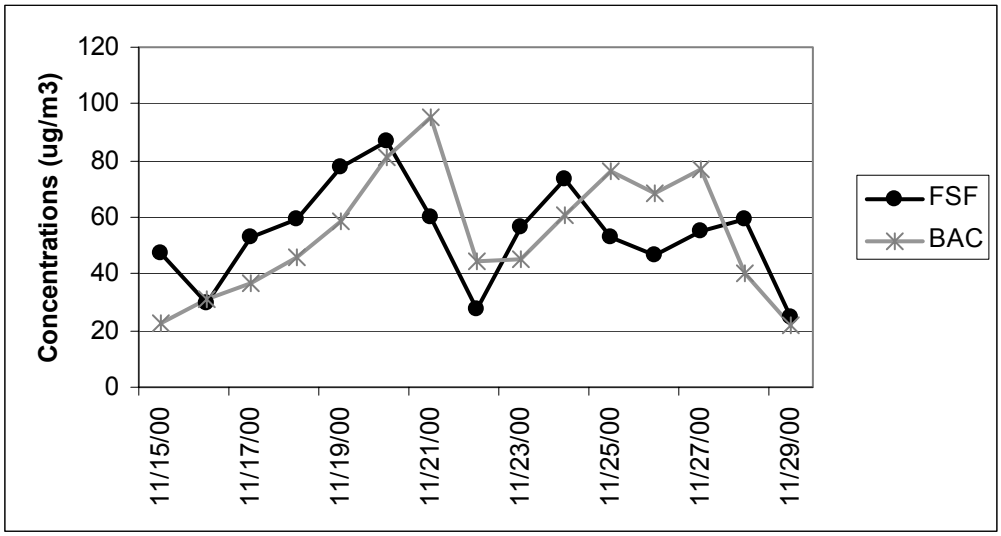
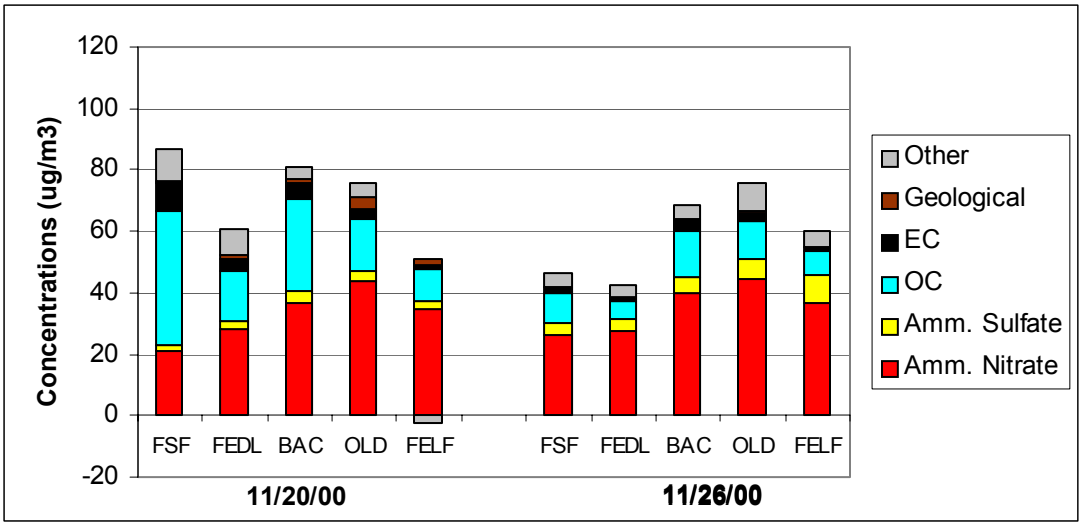


Figure 5-2 $PM_{2.5}$ chemical composition on 11/20/00 and 11/26/00.



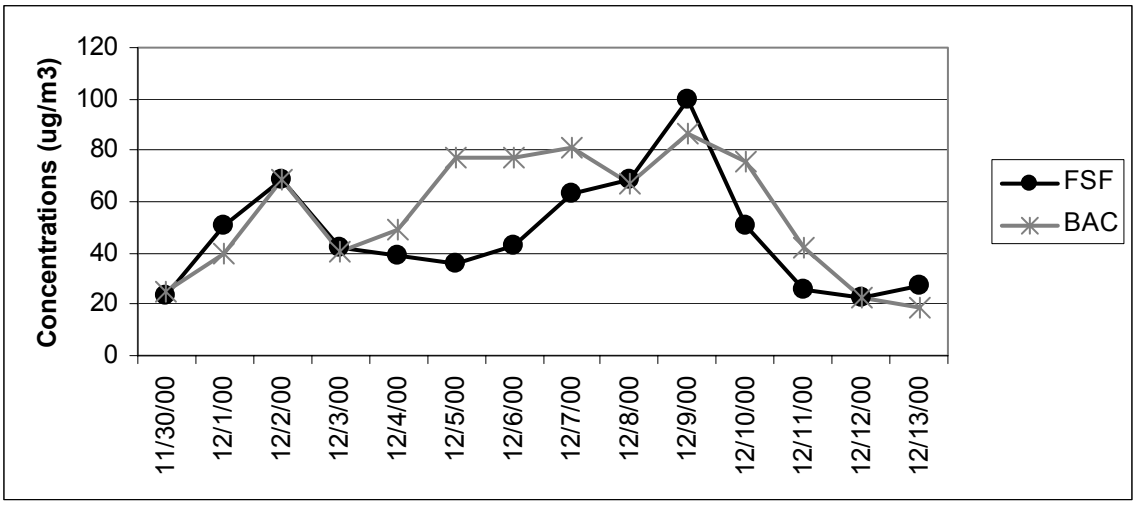
6 NOVEMBER/DECEMBER 2000 EPISODE

The November/December 2000 episode lasted from November 30 through December 13, 2000. It formed following a brief decline in concentrations after the November 2000 episode. On December 3, only three days after the November episode ended, multiple sites in the Valley exceeded the federal $PM_{2.5}$ standard. The characteristics of this episode were somewhat similar to the November episode. Carbonaceous aerosols comprised a larger fraction of the mass at the beginning of the episode, but as the episode evolved, ammonium nitrate concentrations increased and comprised a larger fraction of $PM_{2.5}$ mass.

However, while the carbon concentrations decreased over time during the November episode, the November/December episode showed an increase in both carbon and ammonium nitrate, but with the ammonium nitrate increasing at a greater rate.

During this episode, Bakersfield and Fresno exhibited different temporal patterns (Figure 6-1). Both sites experienced a peak in concentrations on December 2, followed by a decline. While the lower concentrations lasted only one day at Bakersfield, Fresno had five consecutive days with concentrations below the standard. During this episode, Bakersfield reached a peak of 86 $\mu g/m^3$ and had seven days above the standard, while Fresno reached 100 $\mu g/m^3$, but had only three days above the standard. The average concentrations at Bakersfield and Fresno were 55 $\mu g/m^3$ and 47 $\mu g/m^3$ respectively.

Figure 6-1 $PM_{2.5}$ concentrations between 11/30/00 and 12/13/00.



All of the urban monitoring sites, with the exception of Stockton, Merced, and Corcoran, exceeded the $PM_{2.5}$ standard. Concentrations at rural sites remained below the standard throughout this episode, except at Pixley which exceeded the standard with a concentration of 71 $\mu g/m^3$. Although rural sites had lower concentrations than nearby urban sites, they followed the same temporal pattern. For example, Sierra Nevada Foothills had a pattern very similar to Fresno-1st, and Angiola followed Bakersfield's (Figure 6-2). Outside of the San Joaquin Valley, the Chico-Manzanita monitoring site in the Sacramento Valley exceeded the $PM_{2.5}$ standard on December 8 with a concentration of 70 $\mu g/m^3$.

Ammonium nitrate was the largest component of $PM_{2.5}$ mass at all Valley sites except Modesto and Fresno. On December 8 (Figure 6-3) ammonium nitrate concentrations differed by 27 $\mu g/m^3$, ranging from 21 $\mu g/m^3$ at Modesto to 48 $\mu g/m^3$ at Visalia. Carbonaceous aerosols (shown in the graph as a sum of organic and elemental carbon) was the largest component of $PM_{2.5}$ mass at Modesto and Fresno and the second largest component at all other Valley sites.

Carbonaceous aerosols concentrations differed by 23 μg/m^3, ranging from 15 μg/m^3 at Corcoran to 38 μg/m^3 at Modesto.

Figure 6-2 Comparison of urban and rural 24-hour average $PM_{2.5}$ BAM concentrations between 11/30/00 and 12/13/00.

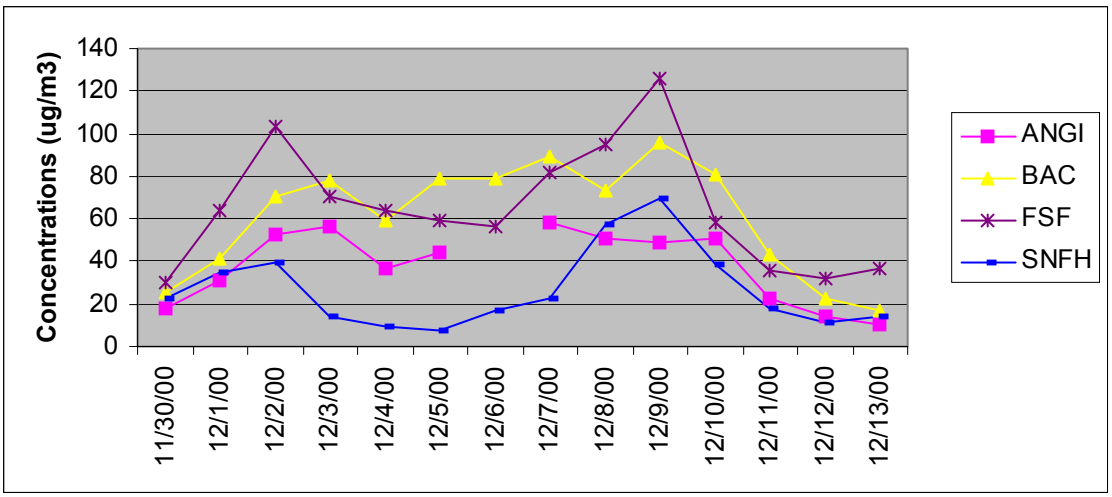
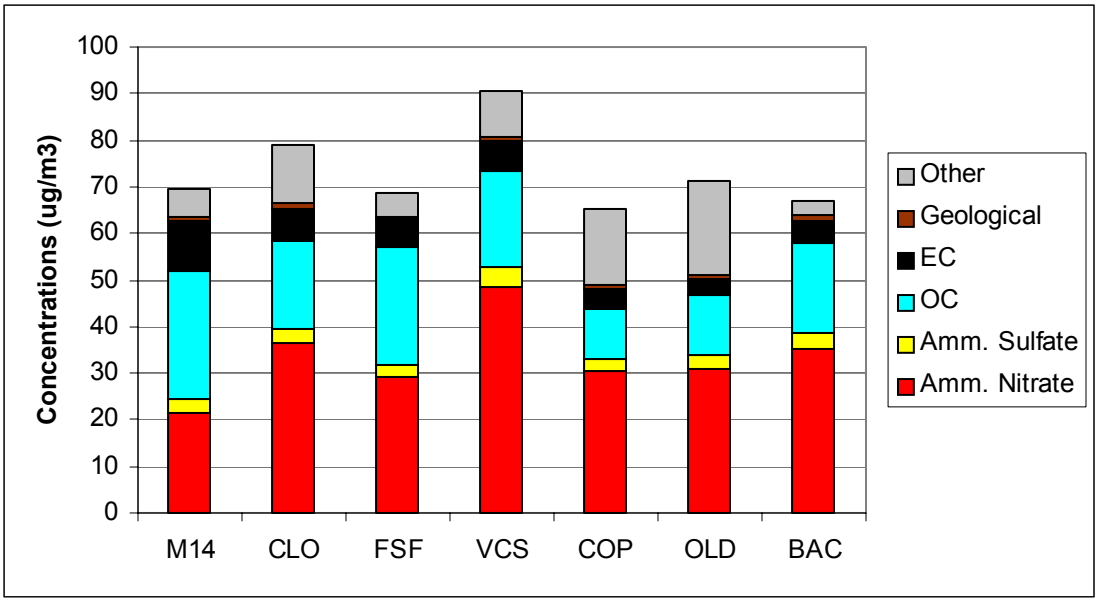


Figure 6-3 Spatial variations in $PM_{2.5}$ chemical components on 12/8/00.



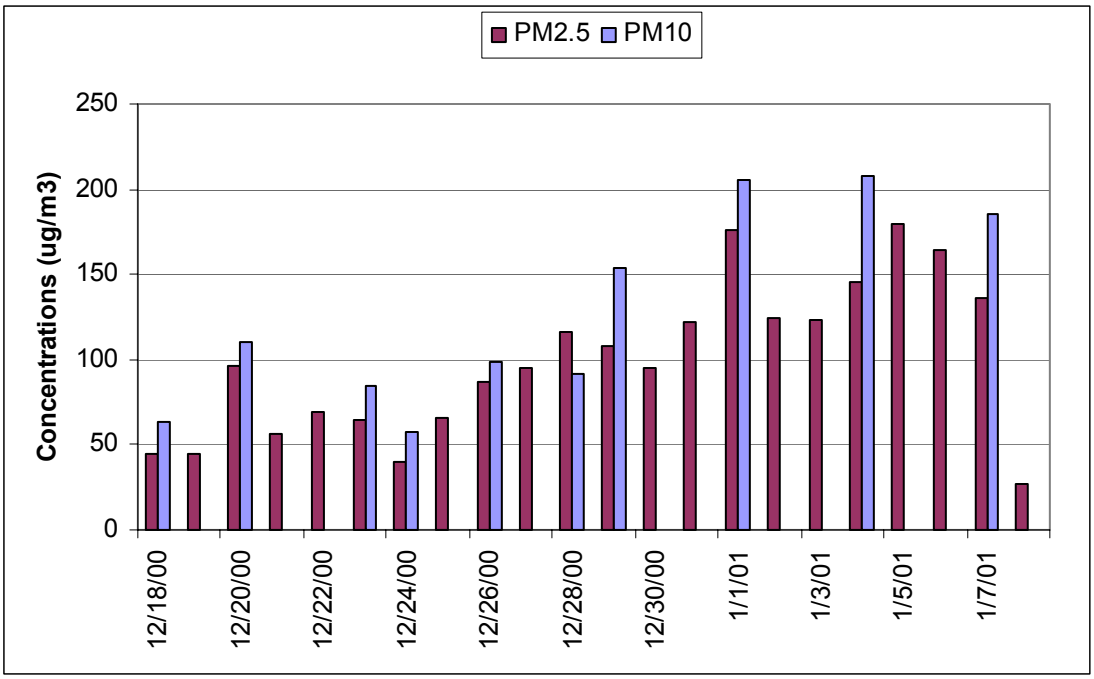
7 DECEMBER 2000 EPISODE

The December 2000 episode lasted from December 18, 2000 through January 8, 2001.

7.1 PM_{10} Concentrations

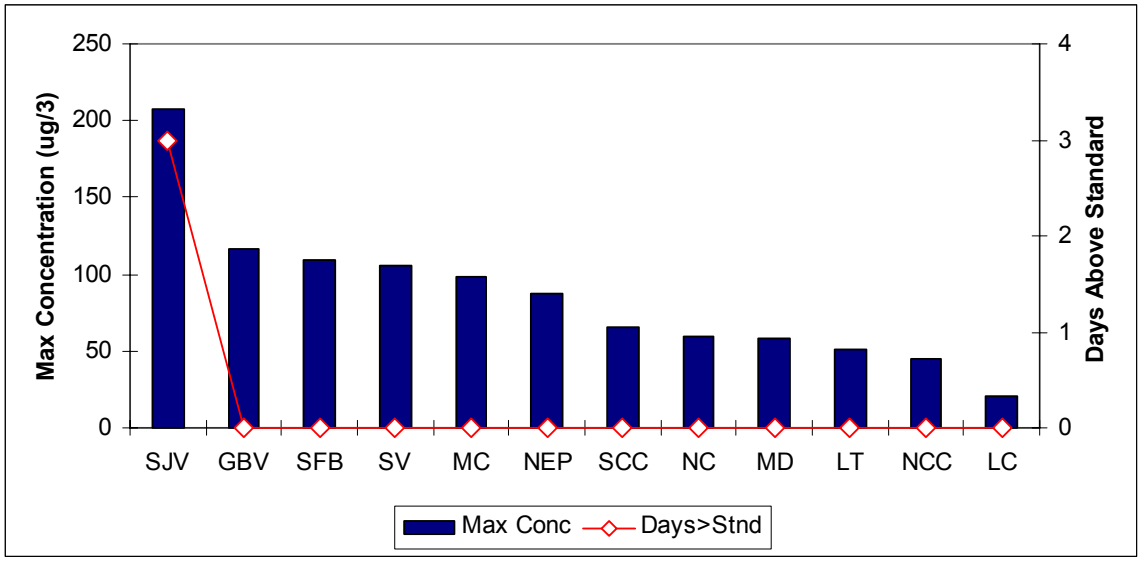
PM_{10} concentrations first peaked on December 20, but the highest 24-hour average of 110 µg/m^3 was still below the federal PM_{10} standard. Figure 7-1 illustrates peak PM concentrations in the San Joaquin Valley. Between December 20 and 24, concentrations declined slightly, only to begin climbing steadily again on December 25. On December 29, a near-exceedance concentration of 153 µg/m^3 was measured at Bakersfield-Golden, but January 1 was the first day with recorded widespread exceedances throughout the San Joaquin Valley (no data were collected on December 30 and 31). Six sites, from Merced in the north to Bakersfield in the south, exceeded the standard. The highest concentration, 208 µg/m^3, was measured at Bakersfield-Golden on January 4, 2001. High concentrations persisted in the Valley until January 6, but most sites peaked on January 5. While a downward trend was visible at many sites on January 7, some sites, including Stockton, Modesto, Hanford, and Corcoran, had just reached their peak.

Figure 7-1 San Joaquin Valley peak PM concentrations between 12/18/00 and 1/8/01.



There were no federal PM_{10} exceedances outside of the San Joaquin Valley. Figure 7-2 illustrates maximum PM_{10} concentrations and days above the federal 24-hour PM_{10} standard in each air basin.

Figure 7-2 Maximum PM_{10} concentrations and days above federal standard between 12/18/00 and 1/8/01.

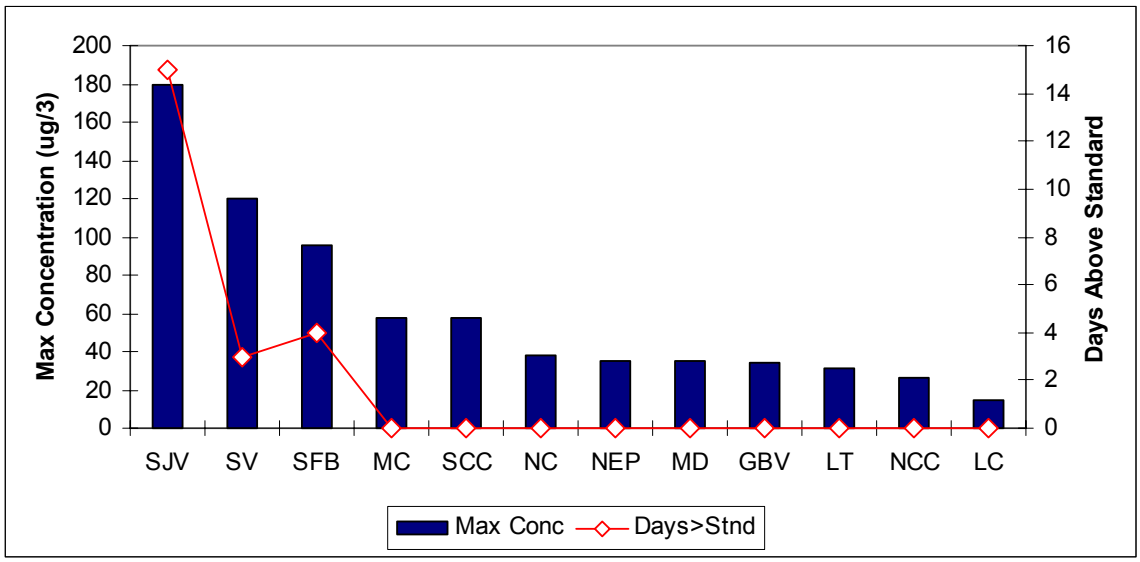


7.2 $PM_{2.5}$ Concentrations

During the December 2000 episode, $PM_{2.5}$ concentrations in the San Joaquin Valley were very high for a number of days. They first exceeded the 24-hour federal $PM_{2.5}$ standard on December 20 when concentrations at Fresno reached almost 100 $\mu g/m^3$ (Figure 7-1). During this early peak, concentrations in the Bakersfield area remained below the standard. Between December 20 and 24, concentrations dropped slightly, only to climb once again between December 25 and January 1. By January 1, most of the urban monitoring sites reached their peak concentrations, which then dropped down slightly on January 2 and plateaued until January 6. The average daily concentration for all 15 urban monitoring sites in the San Joaquin Valley exceeded the $PM_{2.5}$ standard every day from December 28 through January 7. On January 7, concentrations went down slightly, but the complete cleanup took place on January 8, when significant rainfall occurred.

Record high concentrations were measured at many urban as well as rural sites throughout the Valley. The highest concentration, 179 $\mu g/m^3$, was measured on January 5 at Edison. The Fresno area peaked on January 1 with 176 $\mu g/m^3$. Bakersfield reached almost 160 $\mu g/m^3$ twice, first on January 1 and again on January 5. Pixley, with 165 $\mu g/m^3$ measured on January 6, was the highest rural site. Figure 7-3 illustrates maximum $PM_{2.5}$ concentrations and days above the federal 24-hour $PM_{2.5}$ standard in each air basin.

Figure 7-3 Maximum $PM_{2.5}$ concentrations and days above federal standard between 12/18/00 and 1/8/01.



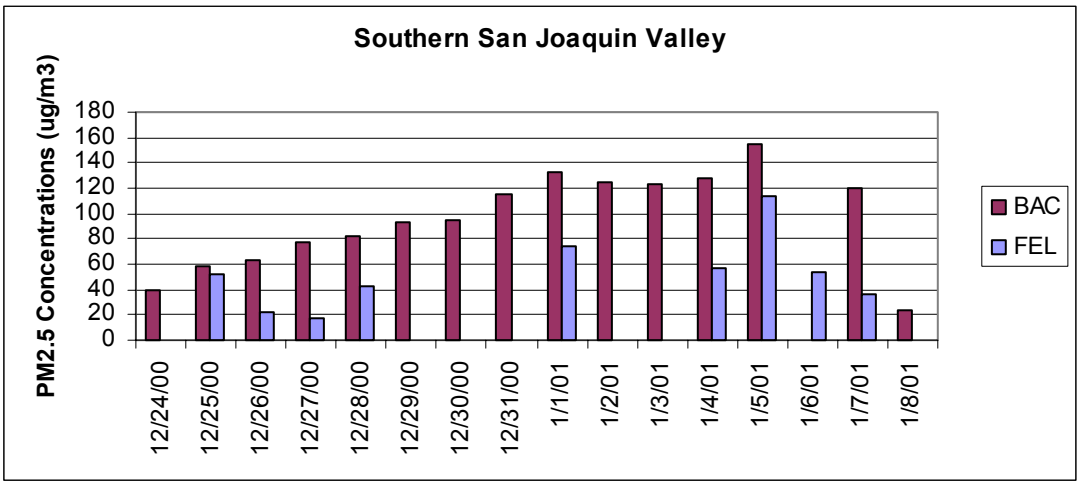
The spatial and temporal patterns of $PM_{2.5}$ concentration depend on geographic location and sources. Different temporal patterns were found in the southern, central, and northern portions of the San Joaquin Valley (Figure 7-4). $PM_{2.5}$ concentrations in the southern portion of the Valley (Bakersfield area) had two strong peaks, the first on January 1 and the second on January 5. While urban site peaks reached similar magnitude, concentrations at rural sites continued to build up until January 5, resulting in much stronger peaks towards the end of the episode. In the central section of the Valley, the difference between urban and rural sites was even more significant. While urban sites had a strong peak on January 1, rural sites, from Southwest Chowchilla in the north to Angiola and Pixley in the south, did not peak until January 6. The northern part of the Valley, from Merced in the south to Stockton in the north, had a weak peak (with concentrations up to 80 $\mu g/m^3$) on December 29, followed by a very strong one (with concentrations almost twice the level of the standard) on January 6 and 7.

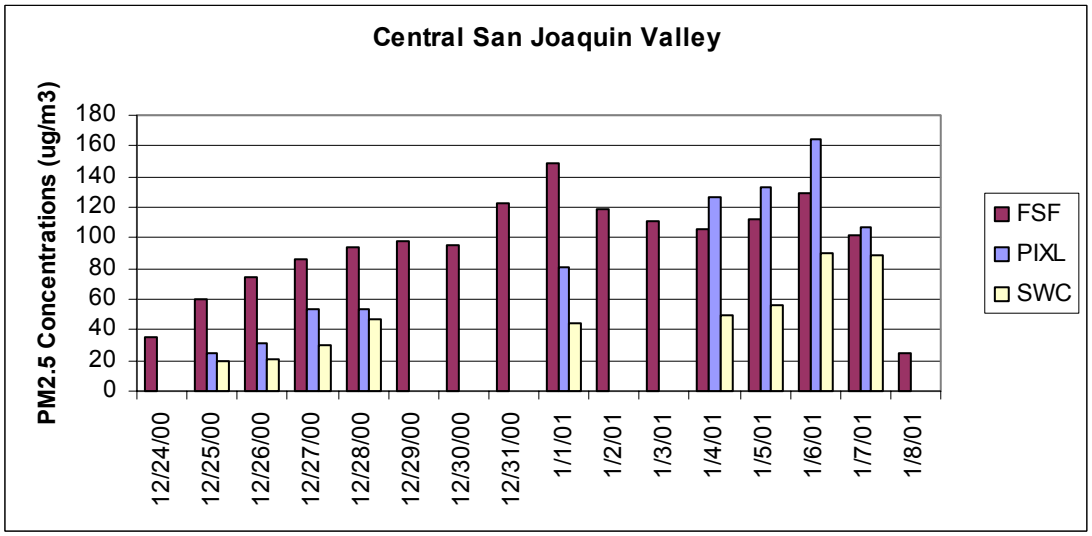
Urban sites in the Sacramento Valley peaked on January 1 and again on January 5, but significant variations of $PM_{2.5}$ mass occurred within an urban area (Figure 7-5). On January 1, carbonaceous aerosols were responsible for a 50 $\mu g/m^3$ difference in $PM_{2.5}$ mass between the two urban Sacramento sites which are less than 10 miles apart (Sacramento-Del Paso Manor and Sacramento-13th Street). The additional 50 $\mu g/m^3$ of carbonaceous aerosols measured at Sacramento-Del Paso Manor indicates significantly larger emissions from woodburning and possibly fireworks compared to Sacramento-13th Street. Hourly $PM_{2.5}$ BAM data shows that the peak 1-hr average $PM_{2.5}$ concentration at Sacramento-Del Paso Manor was 350 $\mu g/m^3$, with the average concentration between 8 p.m. on December 31 and 1 a.m. on January 1 being 300 $\mu g/m^3$.

Rural sites in the Sacramento Valley had a similar temporal pattern but the concentrations were much lower. The highest concentration measured outside of Sacramento was below 60 μg/m^3 on both of the peak days (January 1 and 4).

Monitoring sites in the San Francisco Bay Area Air Basin had two distinct temporal patterns. Some monitoring sites, including San Jose-4th, San Jose-Tully, and San Francisco-Arkansas, appear to be mostly influenced by local sources and therefore had their own temporal patterns. For example, $PM_{2.5}$ mass at San Jose-4th changed very little from December 27 to January 6 and was dominated by carbon. Other sites, including Santa Rosa, Vallejo, Bethel Island, Altamont, and Livermore, may be more impacted by regional PM. They all experienced a significant peak in concentrations on January 7, with concentrations above the $PM_{2.5}$ standard at each site (Figure 7-6). Livermore, with a concentration of 95 μg/m^3, had the highest concentration in the Bay Area.

Figure 7-4 Spatial and temporal variations of $PM_{2.5}$ concentrations between 12/24/00 and 1/8/01.





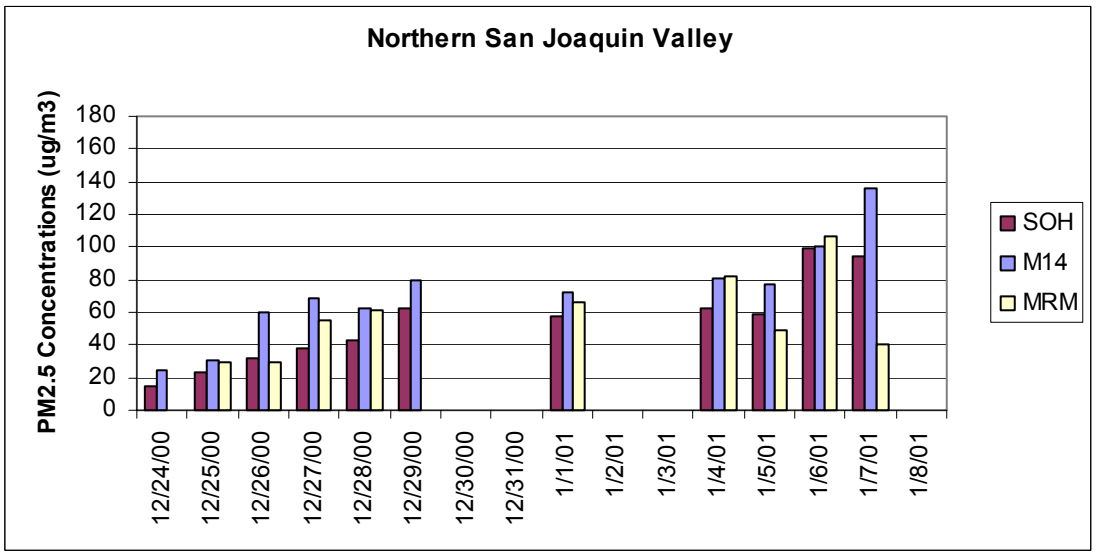


Figure 7-5 Spatial variations of $PM_{2.5}$ carbon concentrations for Sacramento sites during the December 2000 Episode.

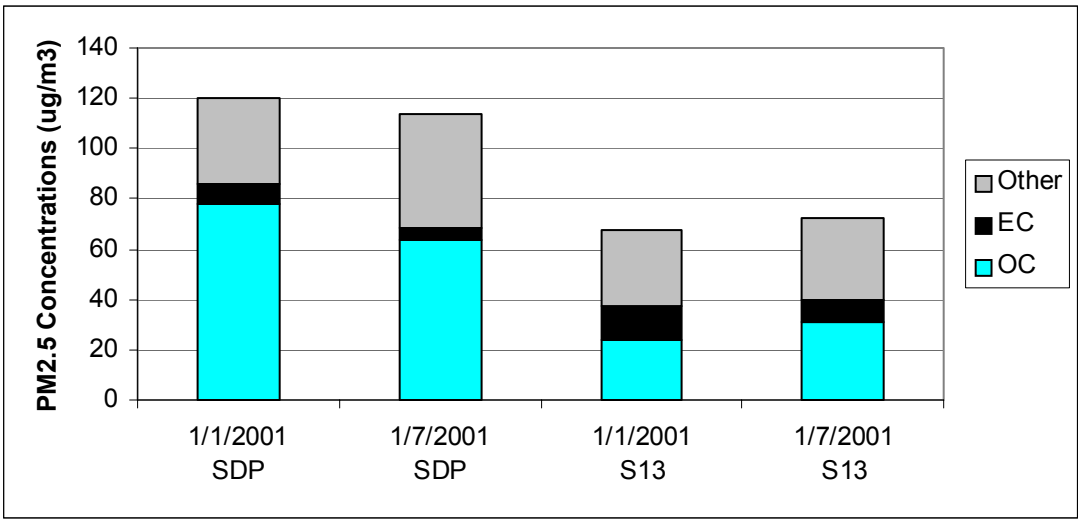
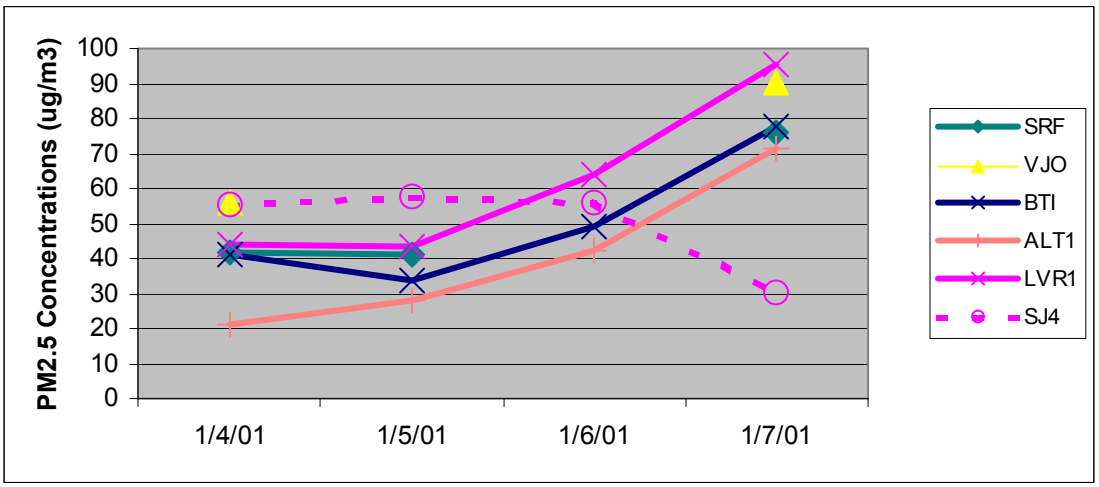


Figure 7-6 $PM_{2.5}$ concentrations at selected Bay Area sites between 1/4/01 and 1/7/01.

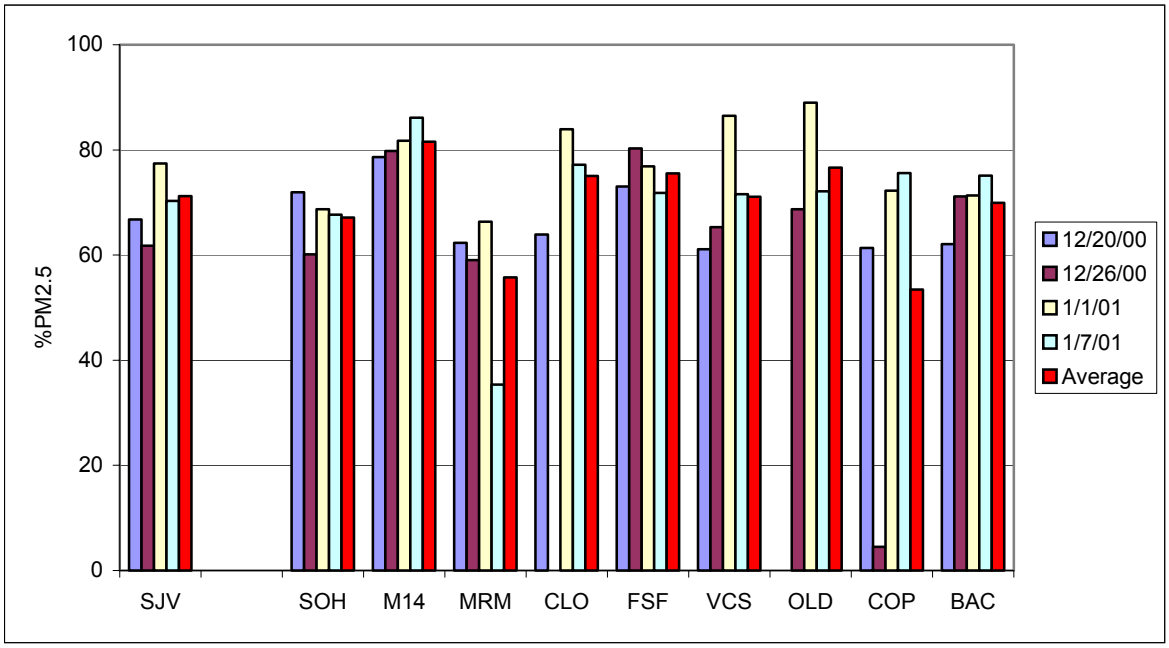


7.3 $PM_{2.5}$ to PM_{10} Ratio

As with the December 1999 episode, the ratio of $PM_{2.5}$ to PM_{10} followed the same general trend shown by $PM_{2.5}$ concentrations. The episode was slower to reach its peak (day 14), but achieved a higher fraction of $PM_{2.5}$ than December 1999. The percentage of PM attributable to $PM_{2.5}$ was approximately 65% at the beginning of the episode, only slightly higher than the previous December (Figure 7-7). Sites in the central portion of the Valley were lower. Around 60% of PM was attributable to PM2.5. In the central portion and parts of the southern Valley, the fine fraction peaked on January 1, day 14. The highest fraction was achieved on this day, when Oildale reached almost 90%. Modesto, the peak site

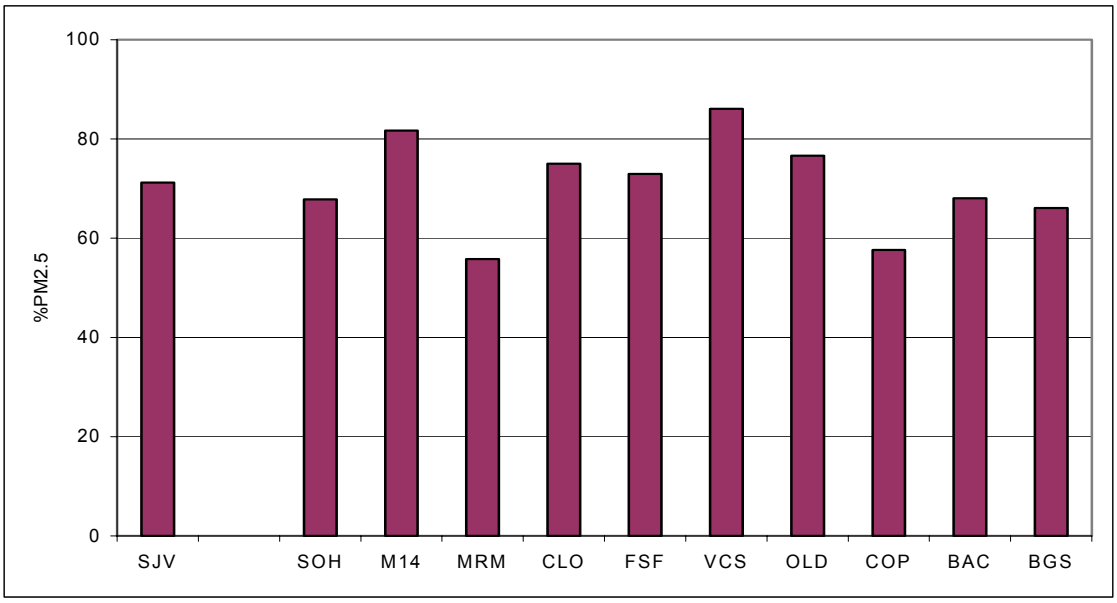
in December 1999, peaked on January 7 with 86%. By the end of the episode, January 7, 2001, ratios were still high, ranging from 50% to over 80%, with a Valley average of approximately 70%.

Figure 7-7 Day-to-day $PM_{2.5}/PM_{10}$ ratio at selected monitoring sites between 12/20/00 and 1/7/01.



The Valley-wide average for this episode was approximately 70% (Figure 7-8), similar to that seen in December 1999. Individual sites, however, showed little uniformity, ranging from less than 60% to almost 90%. The highest sites were in the central portion of the Valley, followed by those in the north.

Figure 7-8 Average $PM_{2.5}/PM_{10}$ ratio at selected monitoring sites between 12/20/00 and 1/7/01.



7.4 Spatial Distribution of $PM_{2.5}$ Concentrations throughout the San Joaquin Valley

This episode started out with two urban areas, Fresno and Bakersfield, exhibiting the highest concentrations. Even though they had a similar mass, the chemical composition data showed that Fresno had more carbon, while Bakersfield had more ammonium nitrate. During the course of this episode, as the urban emissions spread throughout the San Joaquin Valley, concentrations decreased at urban sites and increased at rural sites. This is illustrated in Figure 7-9. Monitoring sites in this graph are presented in a north to south orientation. On January 1, the two urban areas, Bakersfield and Fresno, had the highest concentrations. By January 5, concentrations at rural sites began to reach the same level as urban sites, mostly due to an increase in ammonium nitrate concentrations. By January 7, concentrations at rural sites were similar or even greater than at urban sites. The Northern San Joaquin Valley followed the rural pattern and also peaked at the tail end of the episode, around January 6 or 7.

7.5 Spatial Distribution of $PM_{2.5}$ Concentrations around Fresno Area

The three Fresno urban sites, Fresno-1st, Fresno-Residential, and Fresno-Motor Vehicle, had similar concentrations throughout this episode. However, marked differences were found between urban and rural sites in the area. Initially, surrounding rural sites had lower concentrations. By January 4, the entire area had similar concentrations of ammonium nitrate, about 40 to 50 $\mu g/m^3$, but the

$PM_{2.5}$ mass still varied by more than 60 µg/m^3, with almost all of that difference due to carbon. On January 6, ammonium nitrate concentrations increased throughout the area, especially at rural sites. As a result, $PM_{2.5}$ concentrations were more uniform. Figure 7-10 shows the spatial distribution of $PM_{2.5}$ concentrations and their chemical components in the Fresno area.

Figure 7-9 Spatial distribution of $PM_{2.5}$ chemical components throughout the San Joaquin Valley between 1/1/01 and 1/7/01.

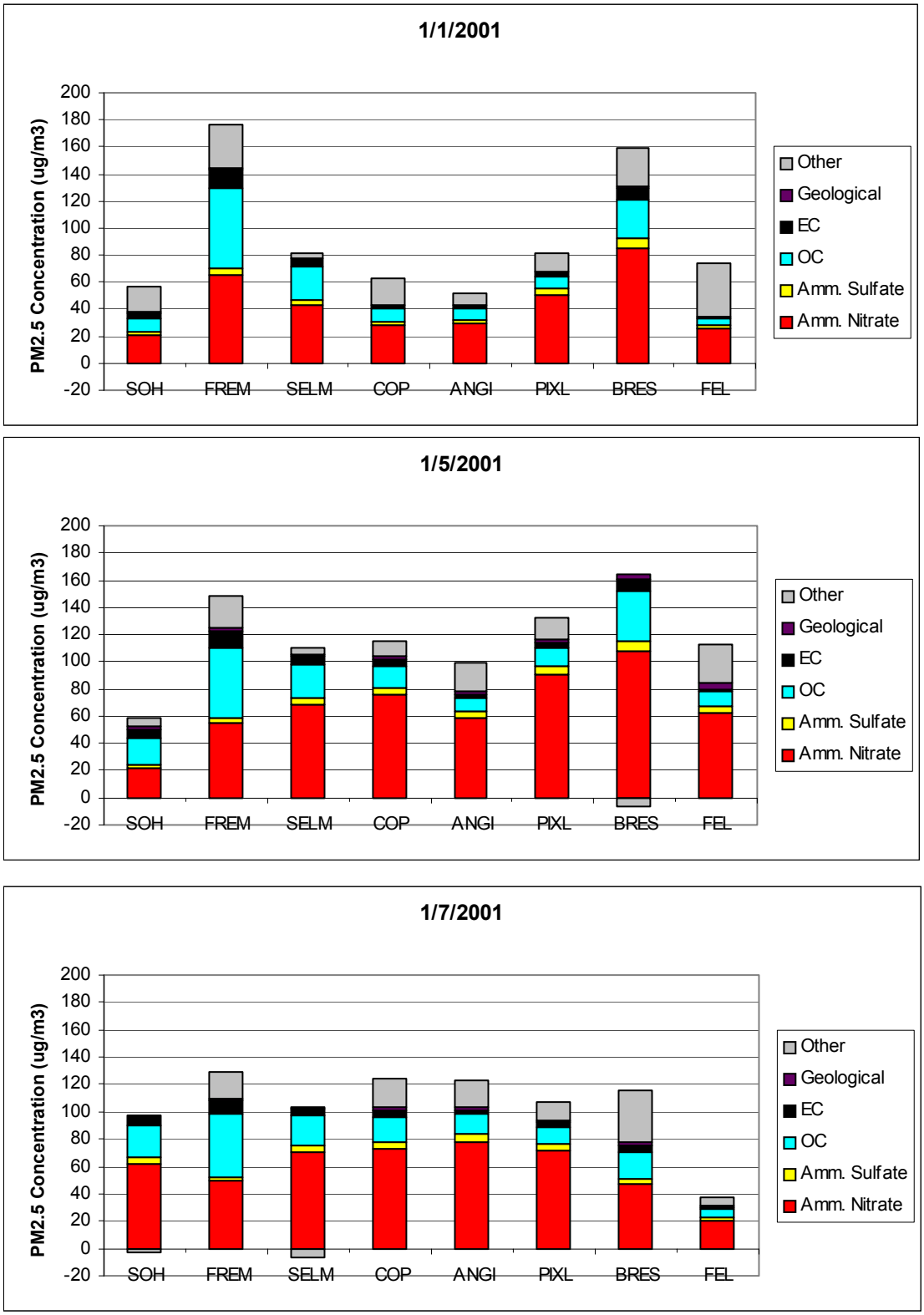
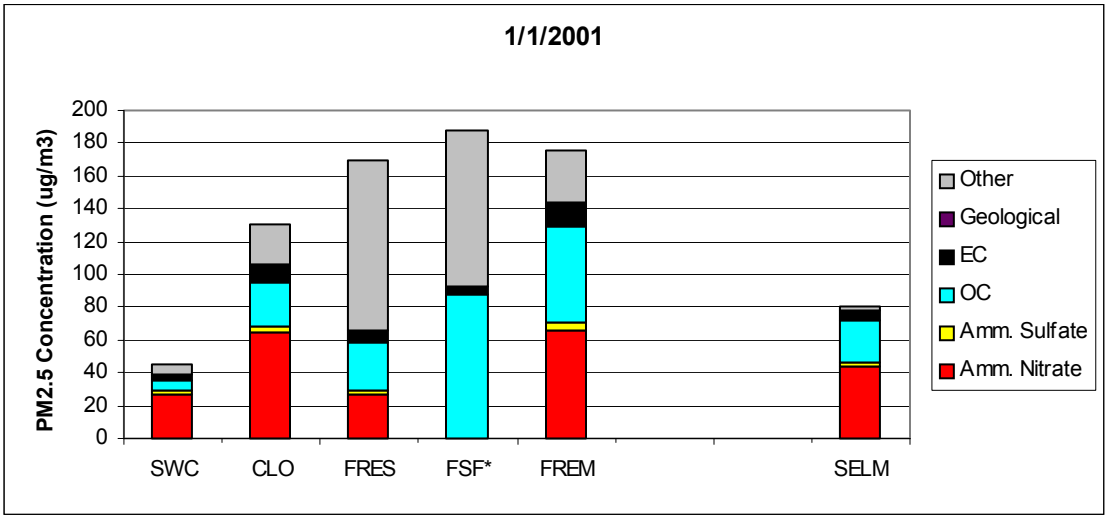
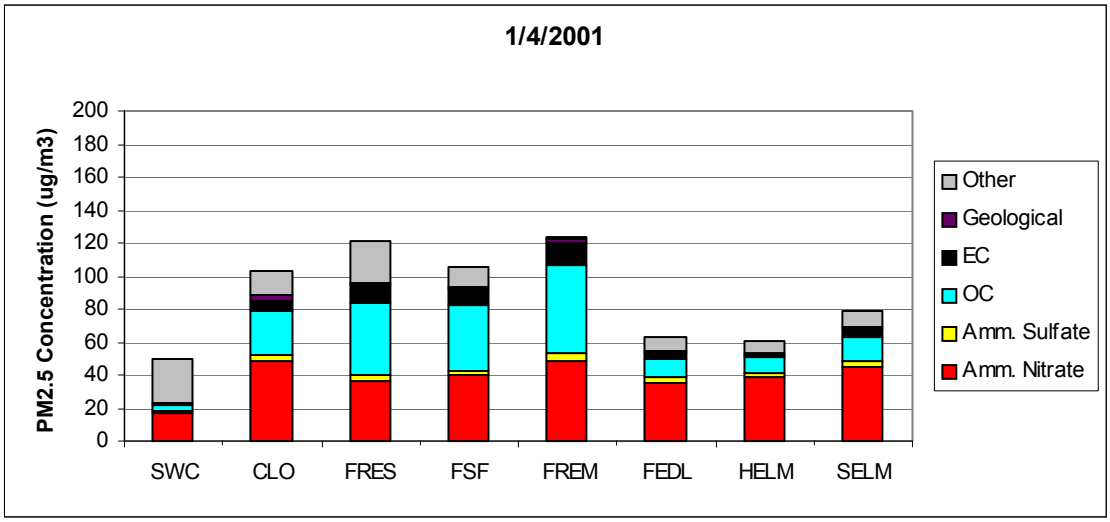
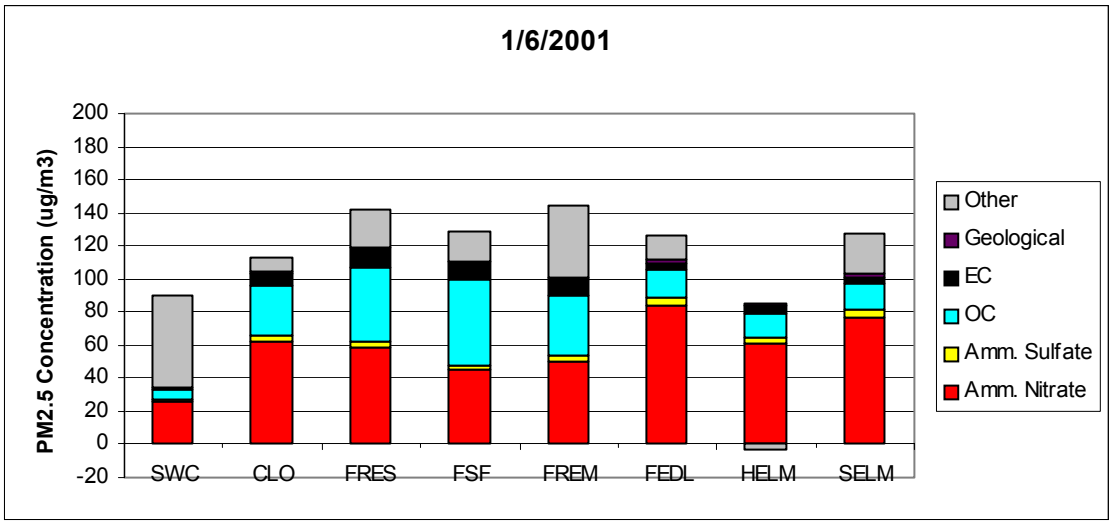


Figure 7-10 Spatial distribution of $PM_{2.5}$ chemical components around the Fresno area between 1/1/01 and 1/6/01.



* Since ammonium nitrate and sulfate data were not available at FSF on 1/1/2001, they are included in the graph as part of "other".





7.6 Spatial Distribution of $PM_{2.5}$ Concentrations around Bakersfield Area

$PM_{2.5}$ concentrations in the Bakersfield area were similar to Fresno, with urban sites starting out higher and rural sites catching up with them at the tail end of the episode (Figure 7-9). While on January 1 concentrations reached up to 160 µg/m^3 at urban sites, rural sites were roughly 50% lower, ranging from 50 µg/m^3 at Angiola to 80 µg/m^3 at Pixley. During the next three days, while concentrations changed very little at urban sites, rural sites experienced a significant increase. By January 7, as the episode spread to the north, rural sites north of Bakersfield experienced higher concentrations than Bakersfield urban sites.

7.7 Comparison of Daily $PM_{2.5}$ Data from Fresno and Bakersfield

On the surface, $PM_{2.5}$ concentrations at Bakersfield and Fresno look similar. Both sites reached a maximum $PM_{2.5}$ concentration of about 150 µg/m^3 and had an average concentration for December 25 through January 7 of 104 µg/m^3, with only slightly more day-to-day variations at Bakersfield. Each site also had a similar number of exceedance days (13 at Fresno and 12 at Bakersfield). The main difference was that Fresno peaked earlier and stayed higher than Bakersfield until January 1 (Figure 7-11). After January 1, concentrations at Bakersfield exceeded Fresno and stayed higher until the end of the episode. Chemical composition data revealed even more significant differences between the sites. Even though both sites had similar $PM_{2.5}$ mass, their chemical composition was different. The dominant component of the $PM_{2.5}$ mass at Fresno was carbonaceous aerosols and at Bakersfield was ammonium nitrate. Between January 1 and 7, 24-hour average ammonium nitrate concentrations (calculated using continuous nitrate data) were, on average, 30 µg/m^3 higher at Bakersfield than at Fresno (Figure 7-12).

Figure 7-11 Comparison of $PM_{2.5}$ concentrations at Fresno and Bakersfield between 12/18/00 and 1/8/01.

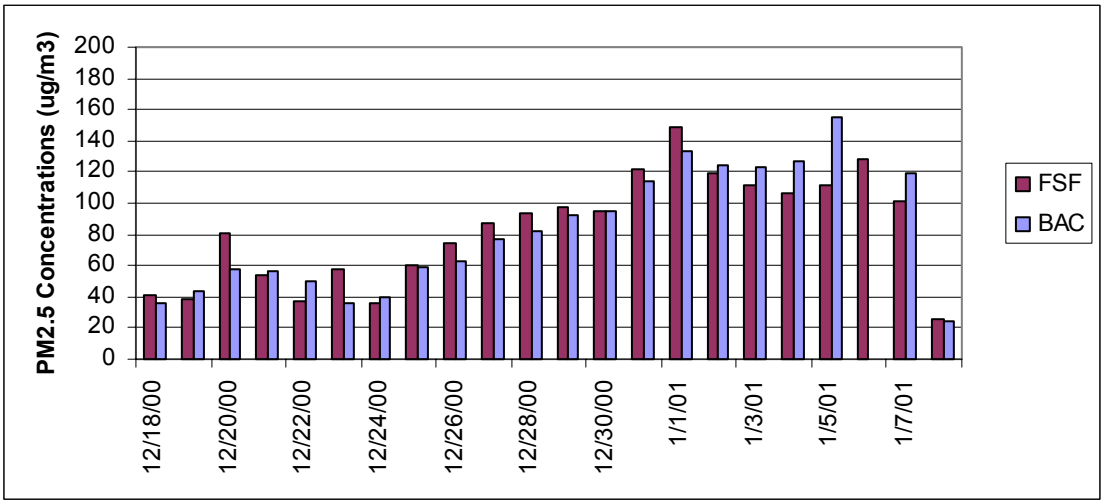
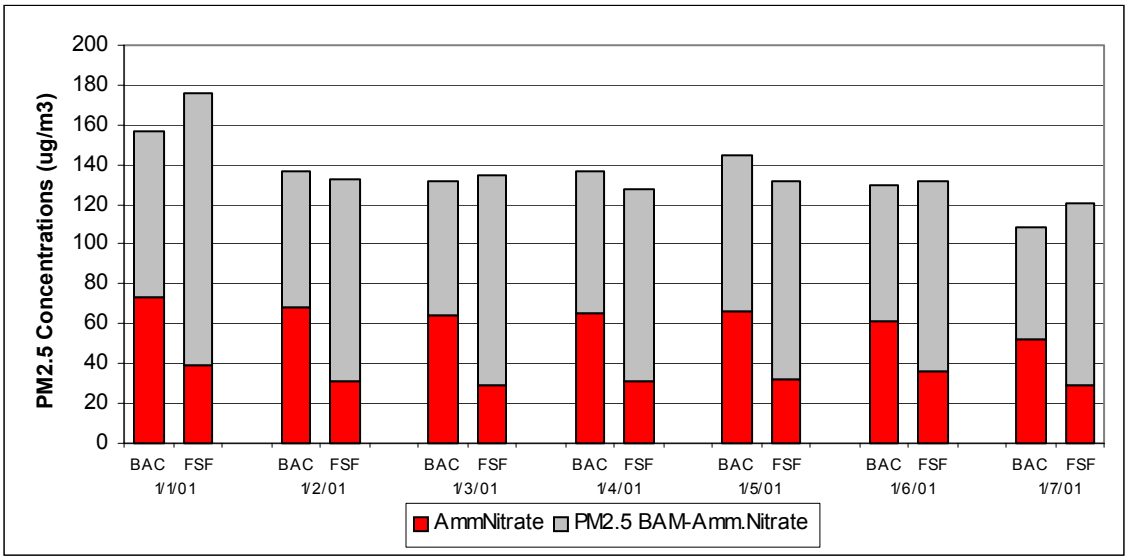


Figure 7-12 Comparison of $PM_{2.5}$ ammonium nitrate concentrations at Fresno and Bakersfield between 1/1/01 and 1/7/01.



7.8 $PM_{2.5}$ Chemical Composition

The average $PM_{2.5}$ chemical composition in the San Joaquin Valley was dominated by ammonium nitrate, which comprised more than 50% of the $PM_{2.5}$ mass. Organic and elemental carbon combined were the second largest component, comprising about 30% of the mass. The remaining mass included less than 5% ammonium sulfate and less than 2% geological material, with the rest unknown. Ammonium nitrate concentrations as well as carbon concentrations showed significant temporal and spatial variations, which accounted for the observed variations in PM2.5 mass.

7.8.1 Ammonium Nitrate

Ammonium nitrate concentrations in the San Joaquin Valley show significant day-to-day variations, with the highest basin-wide average concentration of almost 60 $\mu g/m^3$ found on January 5 and 6. Concentrations at urban sites in the Bakersfield and Fresno areas increased steadily from December 23, 2000 through January 1, 2001. However, between January 1 and 6, concentrations remained fairly constant. Ammonium nitrate concentrations at rural sites, on the other hand, continued to increase steadily until January 5 or 6, at which point they exceeded urban concentrations. Figure 7-13 compares ammonium nitrate concentrations at Bakersfield, shown as a line graph, to concentrations measured at surrounding rural sites, shown as bar graphs. Figure 7-14 shows a similar comparison for the Fresno area.

Figure 7-13 $PM_{2.5}$ ammonium nitrate concentrations in the Bakersfield area between 12/26/00 and 1/7/01.

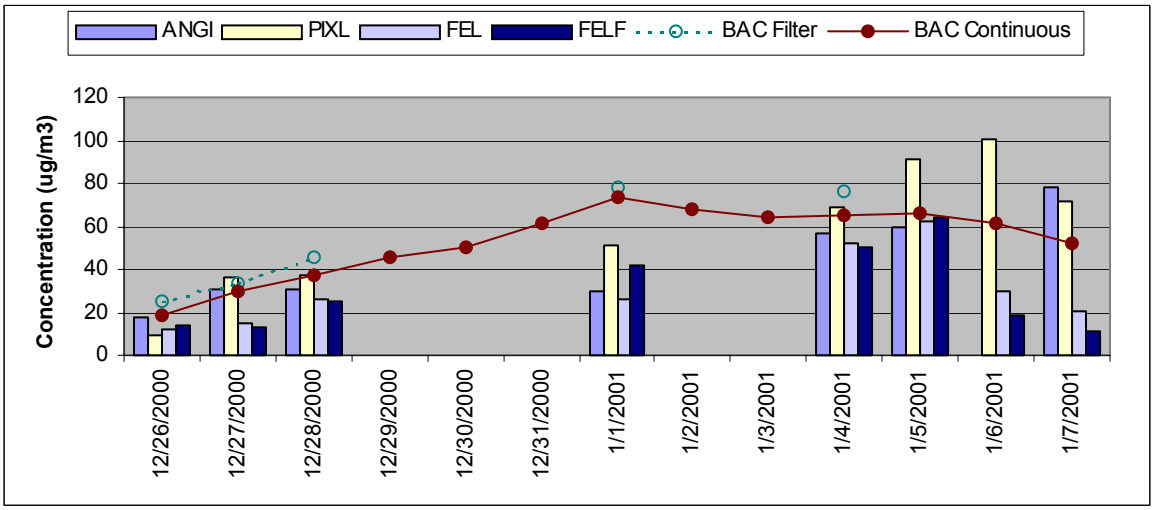
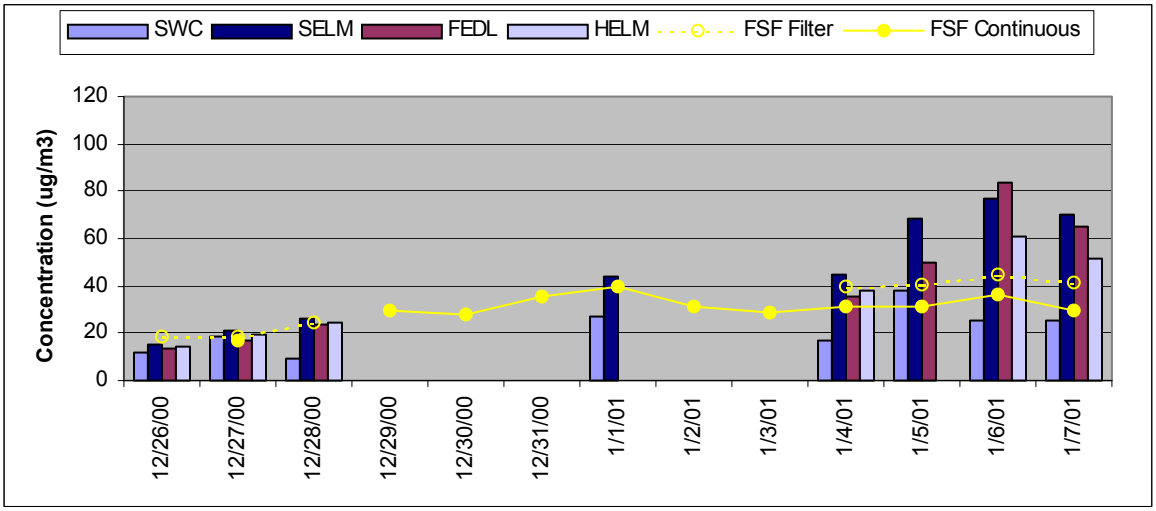


Figure 7-14 $PM_{2.5}$ ammonium nitrate concentrations in the Fresno area between 12/26/00 and 1/7/01.



With the exception of the very end of the episode, on most days ammonium nitrate concentrations were lower at rural sites compared to urban. However, they consistently comprised a larger fraction of the $PM_{2.5}$ mass. Between January 1 and 7, the average ammonium nitrate constituted 10% more mass in rural areas than urban. Carbon, on the other hand, was about 10% lower at rural sites than urban. The relative chemical composition at rural sites was consistent from day to day and from site to site, with more ammonium nitrate than carbon. Urban sites on the other hand were more dissimilar. Bakersfield and Fresno are examples of two urban areas with similar $PM_{2.5}$ concentrations, but dissimilar composition. As discussed in Section 7.7, $PM_{2.5}$ mass was dominated by

ammonium nitrate at Bakersfield and carbonaceous aerosols at Fresno (Figure 7-15). While Bakersfield had 30% more ammonium nitrate than carbon, Fresno had twice as much carbon as ammonium nitrate. $PM_{2.5}$ concentrations were generally similar within urban areas in the San Joaquin Valley. For example, between January 4 and 7, the three monitoring sites located in the Fresno urban area had similar mass and chemical composition (Figure 7-16). Outside of the San Joaquin Valley, in the San Francisco Bay Area and the Sacramento Valley Air Basins, significant variations in concentrations were found even within an urban area. For example, on January 1, 2001 carbonaceous aerosols concentrations differed by 50 $\mu g/m^3$ at the two Sacramento sites, Sacramento-T Street and Sacramento-Del Paso Manor (Figure 7-5).

Towards the end of the episode (January 5-7, 2001), as southerly winds picked up ahead of the approaching frontal system, ammonium nitrate concentrations increased in the northern San Joaquin Valley, San Francisco Bay Area, and Sacramento Valley Air Basins.

Figure 7-15 Dominant components of the $PM_{2.5}$ mass at Fresno and Bakersfield during the December 2000 Episode.

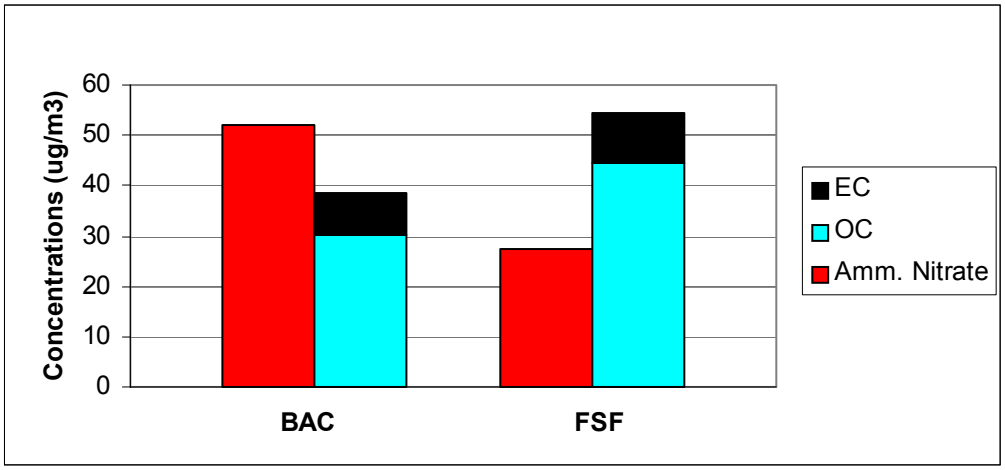
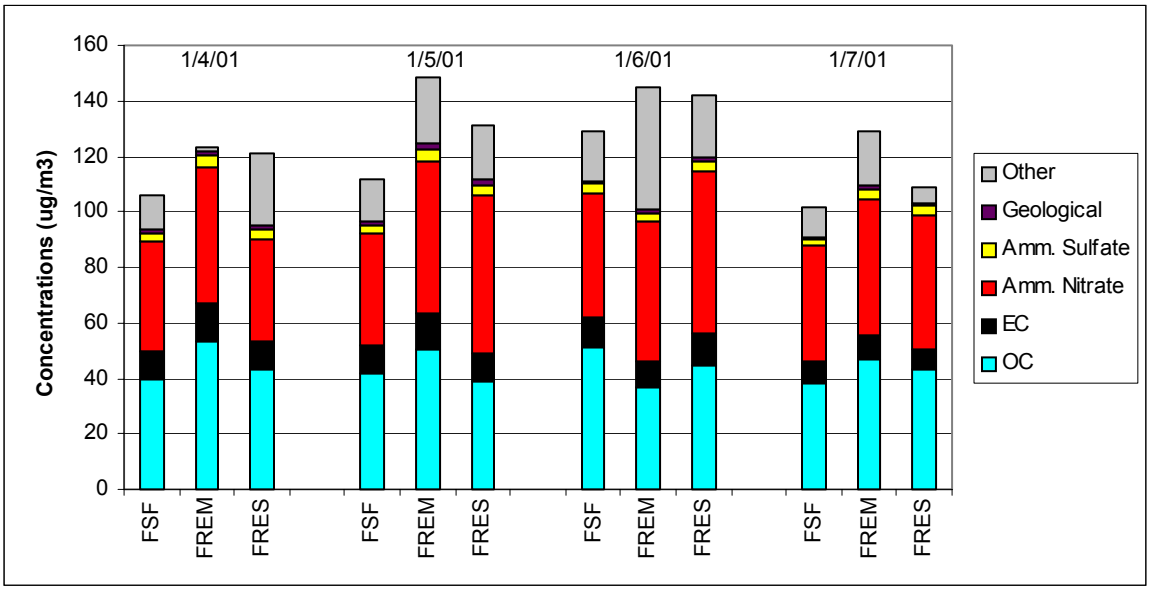


Figure 7-16 $PM_{2.5}$ chemical composition for Fresno urban sites between 1/4/01 and 1/7/01.



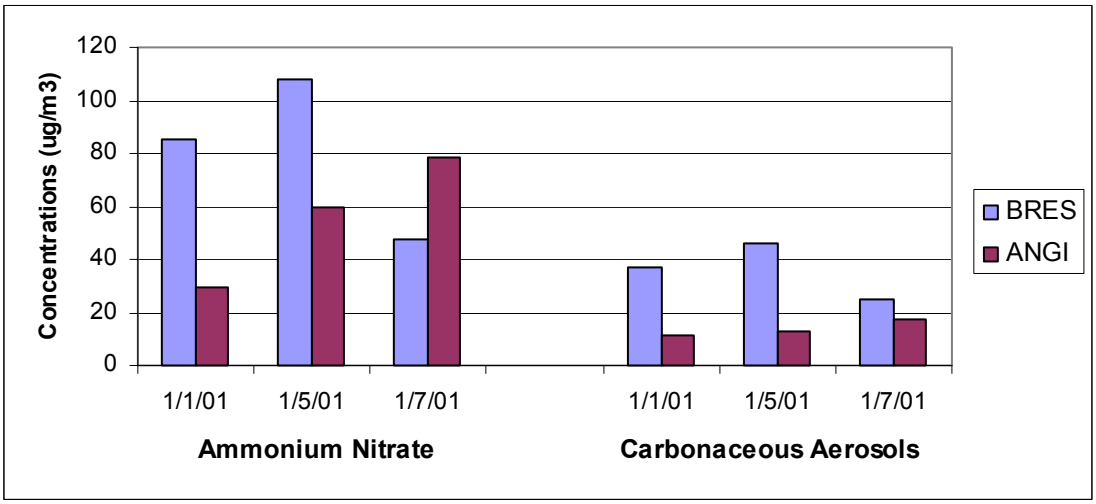
7.8.2 Carbonaceous aerosols

Average carbonaceous aerosols concentrations were 20 µg/m^3 lower at rural sites than urban. Rural carbon also comprised about 10% less mass than urban. While all rural sites were fairly similar with regard to carbon concentrations, differences between urban areas and sometimes even between sites within urban areas were significant. The Fresno area had the highest carbon concentrations, with an episode-average concentration ranging from 50 to 60 µg/m^3. The highest carbon concentration, 92 µg/m^3, was found on January 1 at Fresno-1st. Carbonaceous aerosols concentrations were significantly lower in the Bakersfield area, with an average concentration of about 35 µg/m^3, and a peak of less than 50 µg/m^3. The Sacramento area, with up to 50 µg/m^3 difference in carbonaceous aerosols concentrations between the two urban sites, was a rather unique example of carbon variations within an urban area. The San Francisco Bay Area had a few days with carbonaceous aerosols concentrations in excess of 40 µg/m^3, with the highest concentrations found at San Jose-4th.

While ammonium nitrate concentrations at rural sites more than doubled during this episode, carbonaceous aerosols concentrations changed very little. Towards the end of the episode some rural sites had higher ammonium nitrate concentrations than nearby urban sites. Carbonaceous aerosols, on the other hand, were always higher at urban sites. For example, ammonium nitrate concentrations at Angiola were considerably lower than Bakersfield-Residential

on January 1, but this was reversed on January 7 (Figure 7-17). Carbonaceous aerosols, on the other hand, was always lower at Angiola, by 70% on January 1 and by 30% on January 7.

Figure 7-17 Comparison of chemical components at urban and rural sites in the Bakersfield area between 1/1/01 and 1/7/01.



7.9 PM_{10} Chemical Composition

The differences in PM_{10} chemical composition were significant. The Fresno area stood out as having equal fractions of carbon and ammonium nitrate, while ammonium nitrate dominated the rest of the Valley. In Figure 7-18 Fresno-Drummond represents chemical composition in the Fresno area while Bakersfield-Golden represents the rest of the Valley. Ammonium nitrate concentrations were uniform within an urban area, but highly variable across the Valley, with differences of up to 50 $\mu g/m^3$. On January 4, 2001, depending on the location, PM_{10} mass included 30% to 50% ammonium nitrate, 15% to 30% carbonaceous aerosols, and about 20% geological material (Figure 7-19). Geological material was least variable on a percent basis but its concentration ranged by about 20 $\mu g/m^3$ between sites. The geological fraction, however, was necessary for exceeding the PM_{10} standard. Even when the PM_{10} concentrations reached 208 $\mu g/m^3$, the ammonium nitrate and carbon concentrations combined were not sufficiently high to violate the standard.

Figure 7-18 Comparison of PM_{10} chemical composition for the Fresno and Bakersfield sites on 1/4/01.

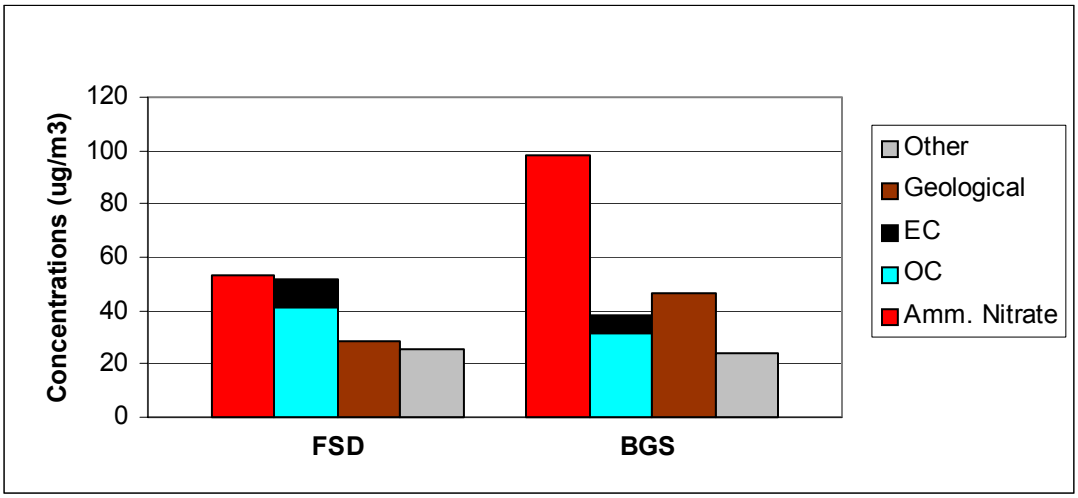
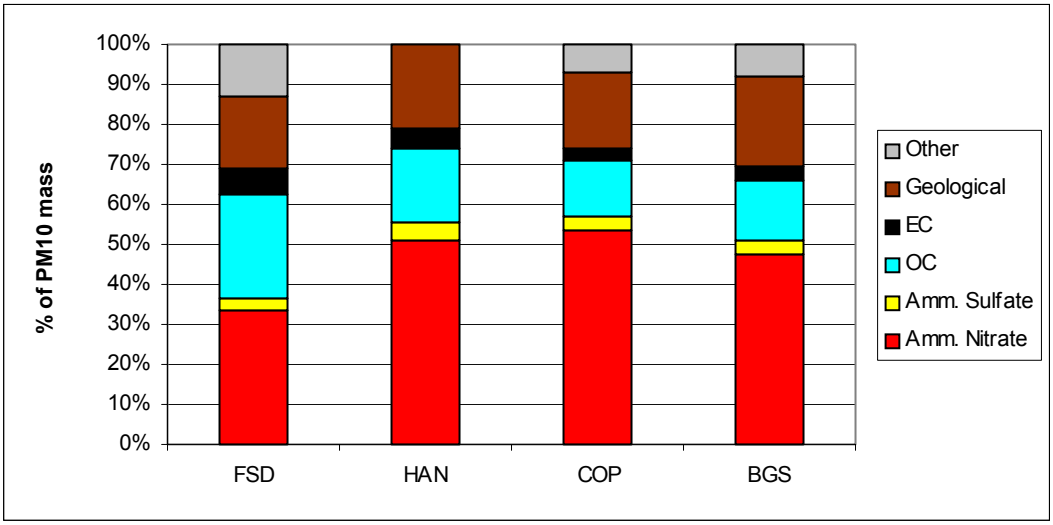


Figure 7-19 Spatial variations in PM_{10} chemical composition on 1/4/01.



7.10 Summary

The December 2000 episode was the most significant particulate matter episode captured during CRPAQS due to its duration, magnitude, and spatial extent. The San Joaquin Valley experienced record high PM_{10} and $PM_{2.5}$ levels. The PM_{10} concentration of 208 µg/m^3, captured at Bakersfield–Golden on January 5, 2001, was the highest PM_{10} measurement in the San Joaquin Valley in recent years. PM_{10} exceedances were also found at monitoring sites that have not exceeded the standard in recent years, such as Clovis and Modesto. $PM_{2.5}$ exceedances were widespread, prolonged, and very high in magnitude. Both Fresno and

Bakersfield experienced almost two weeks of $PM_{2.5}$ concentrations above the standard, with concentrations on many of these days more than twice the standard level.

The area most affected by this episode stretched from Bakersfield in the south to Fresno in the central San Joaquin Valley. The long duration of the episode and the buildup and spread of concentrations in the northerly direction were primarily responsible for the widespread exceedances. The effect of spread on the $PM_{2.5}$ concentrations is reflected in the delayed peak observed at rural sites. A similar delay was also observed at urban and rural sites in the northern San Joaquin Valley and the Bay Area.

The typical $PM_{2.5}$ exceedance in the San Joaquin Valley was dominated by ammonium nitrate, which comprised almost 50% of the $PM_{2.5}$ mass. Organic and elemental carbon was the second largest component, comprising about 32% of the mass. The contribution of ammonium sulfate and geological material was very small.

8 JANUARY 2001 EPISODE

The January 2001 episode lasted from January 12 through January 24, 2001. During this period $PM_{2.5}$ concentrations with the exception of Stockton exceeded the federal $PM_{2.5}$ standard at all urban monitoring sites. Fresno and Bakersfield had similar patterns and achieved similar maximum concentrations of 103 $\mu g/m^3$, but the episode was much stronger at Fresno (Figure 8-1). Fresno had more exceedance days (seven versus three at Bakersfield), and higher episode-average concentrations (70 $\mu g/m^3$ versus 55 $\mu g/m^3$ at Bakersfield). Rural exceedances were limited to two sites, Pixley and Angiola. However, these two sites experienced a very strong episode, with up to four days above the standard and concentrations over 90 $\mu g/m^3$. Their temporal pattern and the magnitude of concentrations resembled urban monitoring sites in this area (Figure 8-2).

Figure 8-3 and Figure 8-4 show that $PM_{2.5}$ and PM_{10} concentrations throughout the San Joaquin Valley, with the exception of Modesto, were dominated by ammonium nitrate. At urban locations (Figure 8-4), ammonium nitrate concentrations increased from the north to the south with the peak around the two most southern urban communities, Oildale and Bakersfield.

The Sacramento Valley and the Bay Area also experienced concentrations over the standard and shared some characteristics. In both air basins the exceedances took place on the same days, January 20 and 21, 2001 and resulted from a sudden increase in concentrations, by more than two-fold, between January 19 and 20. The magnitude of concentrations was also similar, 70 $\mu g/m^3$ and 77 $\mu g/m^3$. In the Sacramento Air Basin two monitoring sites, Sacramento-Del Paso Manor and Sacramento-13th Street, exceeded the

standard, with concentrations about 70 µg/m^3. In the Bay Area, the San Francisco-Arkansas site exceeded the standard twice with concentrations of 70 µg/m^3 and 77 µg/m^3, while San Jose-4th, with 63 µg/m^3, came very close. Chemical composition at Sacramento was similar to Fresno, with more $PM_{2.5}$ mass from the carbon fraction than from ammonium nitrate. The chemical composition data for Bay Area exceedance days are not available.

Figure 8-1 $PM_{2.5}$ concentrations between 1/12/01 and 1/24/01.

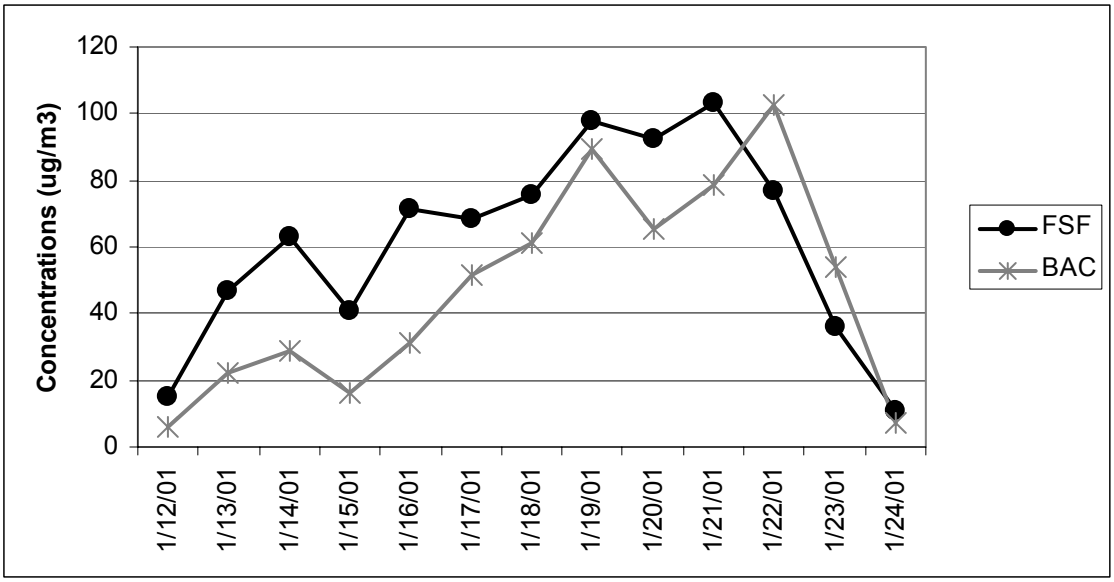


Figure 8-2 Comparison of urban and rural concentrations between 1/12/01 and 1/24/01.

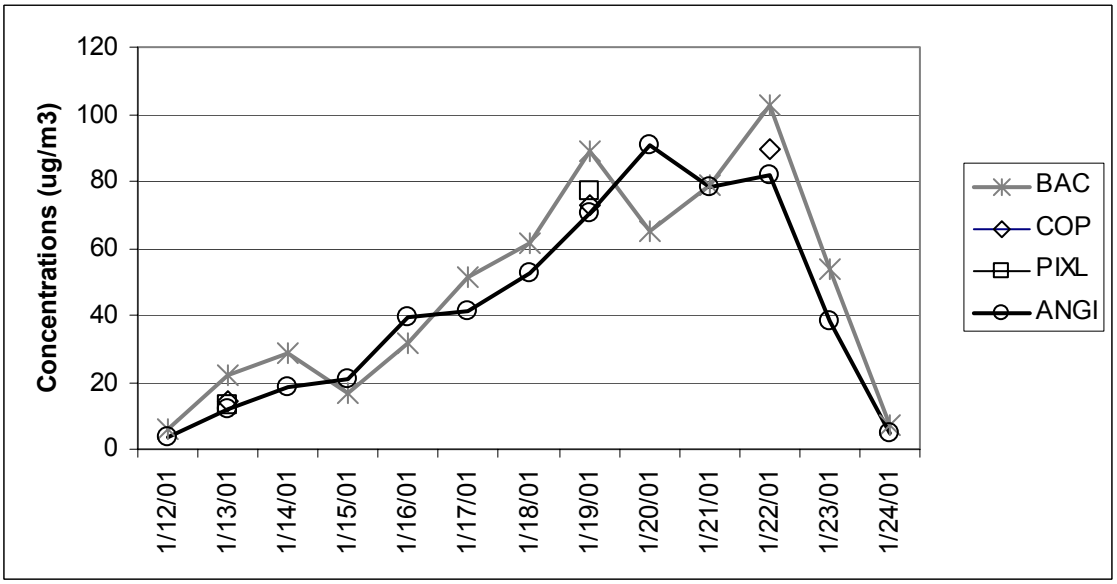


Figure 8-3 Spatial distribution of $PM_{2.5}$ chemical components on 1/19/01.

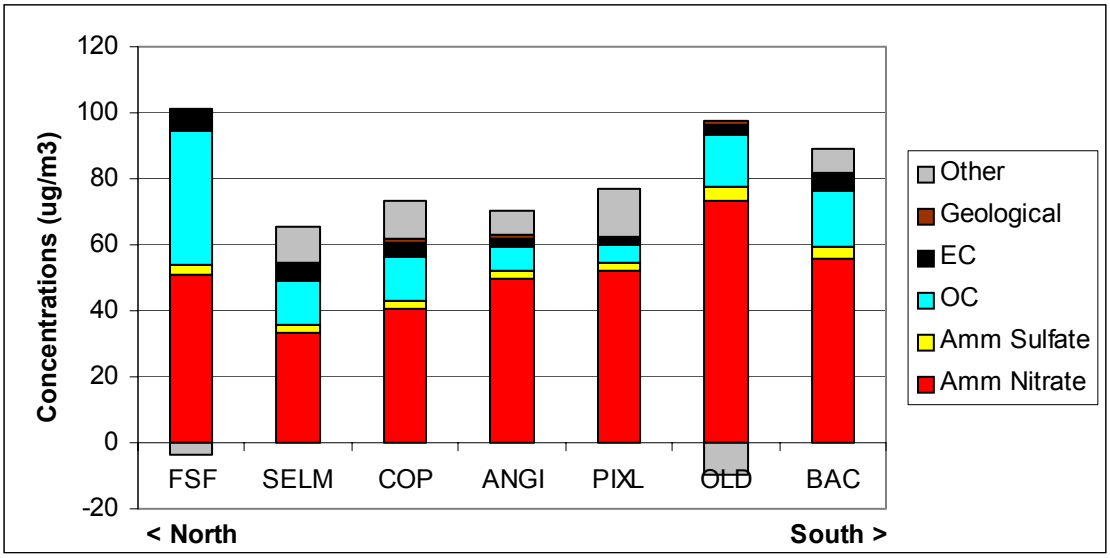
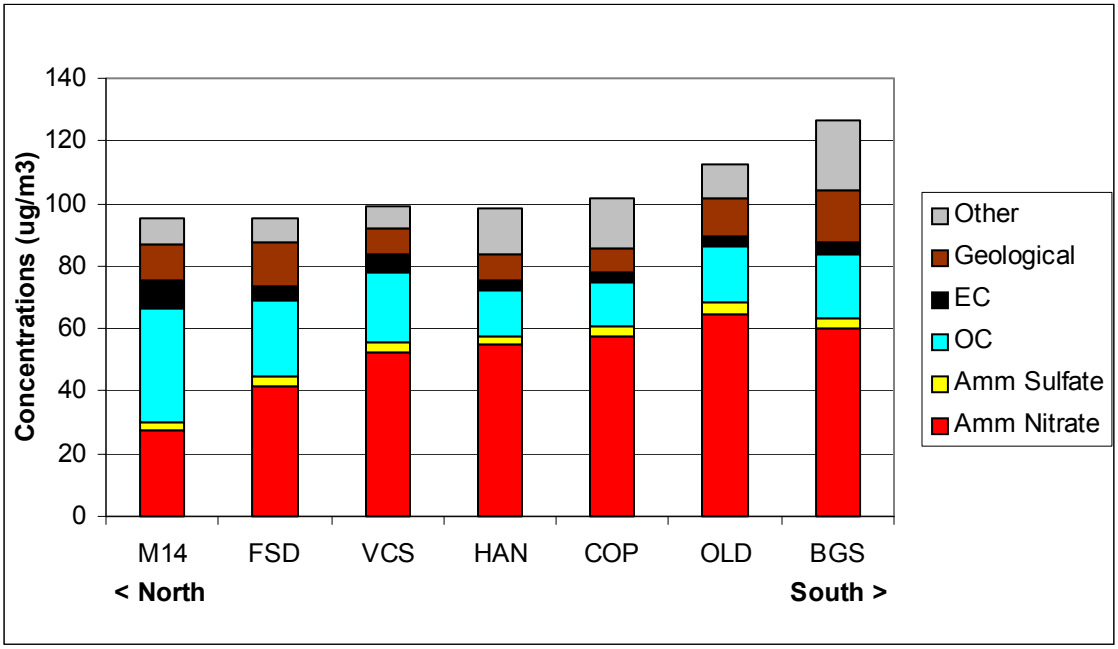


Figure 8-4 Spatial distribution of PM_{10} chemical components on 1/22/01.



9 JANUARY/FEBRUARY 2001 EPISODE

The January/February 2001 episode lasted from January 26 through February 7, 2001. During this period, monitoring sites in the central and southern San Joaquin Valley exceeded the $PM_{2.5}$ 24-hour standard, while the northern Valley remained low. The two highest sites, Fresno and Bakersfield, exhibited similar temporal patterns and achieved similar concentrations (an episode maximum of over 100 $\mu g/m^3$ and an average of 65 $\mu g/m^3$). Pixley and two Fellows sites (Fellows and Foothills above Fellows) were the only rural sites that reached $PM_{2.5}$ concentrations above the federal $PM_{2.5}$ standard. $PM_{2.5}$ concentrations in the Sacramento Valley and San Francisco Bay Area remained below the standard.

The chemical composition data are only available through February 3, one or two days before concentrations reached their maximum. Organic and elemental carbon in the Fresno area and ammonium nitrate in the Bakersfield area drove the buildup in concentrations. Organic and elemental carbon concentrations varied ten-fold, from less than 6 $\mu g/m^3$ at Stockton to 60 $\mu g/m^3$ at Fresno. The ammonium nitrate concentrations were just as variable, ranging from 1 $\mu g/m^3$ at Stockton to 57 $\mu g/m^3$ at Fellows. It is interesting to note that the ammonium nitrate concentration at Fellows was higher than at Bakersfield.

Figure 9-1 $PM_{2.5}$ concentrations between 1/26/01 and 2/7/01.

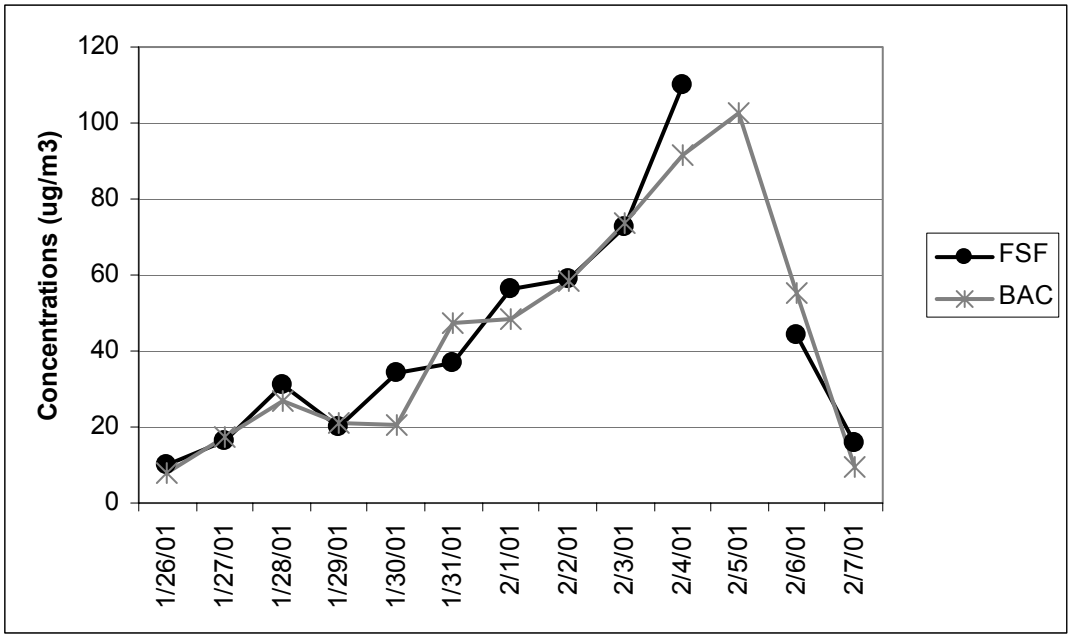
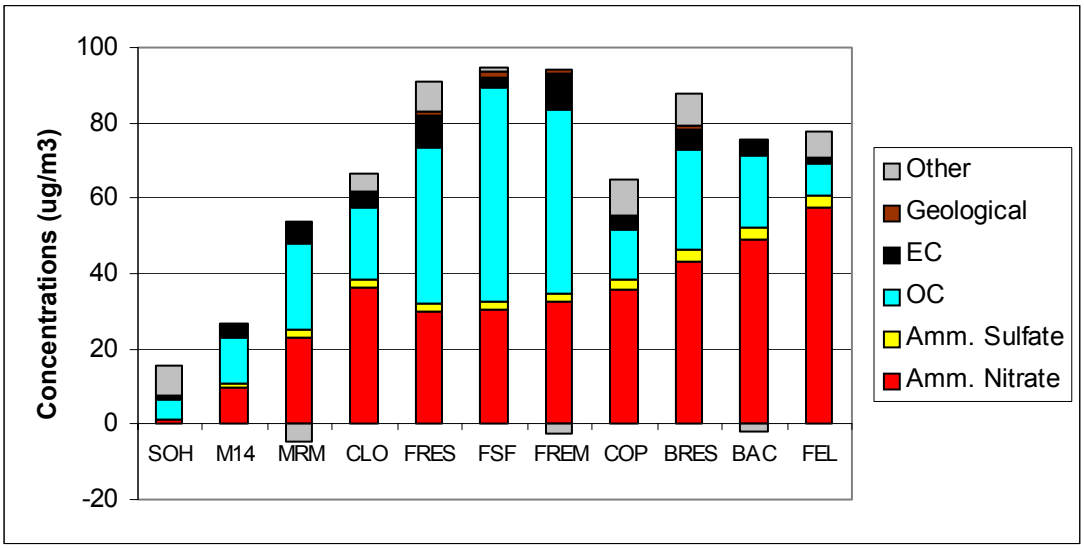


Figure 9-2 Spatial distribution of $PM_{2.5}$ chemical components on 2/3/01.



10 EPISODE COMPARISON

The CRPAQS captured seven particulate matter air quality episodes. Even though each episode was brought on by similar meteorological conditions (strong inversion, low mixing heights, and light and variable winds), subtle differences in meteorology resulted in some unique characteristics. The sections below compare the two most severe episodes, December 1999 and December 2000.

10.1 Duration and Buildup Rate

Each episode, from the beginning of the buildup through the dissolution, lasted about three weeks. During the December 1999 episode, concentrations built rapidly and remained unhealthy for many days. The second episode, December 2000, was characterized by a slower and steadier increase. The consecutive exceedance days started on the second day in 1999 and on the 8th day in 2000 (Figure 10-1). Both episodes finally ended when a storm system moved into the area, breaking down the stagnation period and scavenging particles with rain.

10.2 Strength

The December 1999 episode had more days with unhealthy $PM_{2.5}$ levels but peak concentrations were higher during the second episode. Table 10-1 compares the strength of each episode. $PM_{2.5}$ concentrations in the San Joaquin Valley exceeded the 24-hour standard on 18 days during the 1999 episode and 15 in 2000. Although the December 2000 episode had fewer days above the standard, peak $PM_{2.5}$ and PM_{10} concentrations were higher by about 50 $\mu g/m^3$ and 30 $\mu g/m^3$, respectively.

Figure 10-1 Comparison of $PM_{2.5}$ concentrations during the December 1999 and the December 2000 Episode.

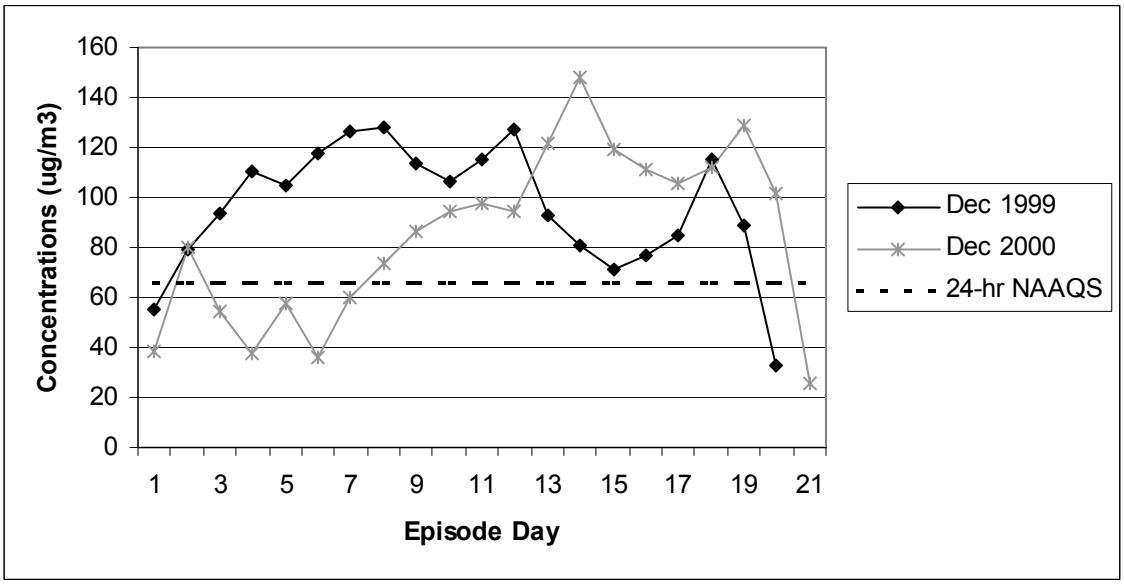


Table 10-1 Episode strength comparison.

Statistics	Episode	
	December 1999	December 2000
Days Exceeding $PM_{2.5}$ Standard	18	15
Days Exceeding $PM_{2.5}$ Standard by More than Two-Fold	0	5
Max PM_{10}	174 µg/m^3	208 µg/m^3
Max $PM_{2.5}$	129 µg/m^3	179 µg/m^3

10.3 Spatial Differences

The December 1999 episode initially centered over the Northern and Central Valley, with $PM_{2.5}$ concentrations from Stockton in the north to Fresno in the south approaching or even exceeding 100 µg/m^3 (Figure 10-2). When the generally light and disorganized winds turned into an enhanced flow from the north, concentrations in the south also increased and several sites, including Corcoran and Pixley, reached 100 µg/m^3. The December 2000 episode started out with high concentrations in the Southern and Central Valley. On January 1, 2001 the peak $PM_{2.5}$ concentrations in the Central and Southern Valley were over two times higher than in the Northern Valley. On the last few days of the episode, the southerly winds increased ahead of an approaching frontal system, spreading concentrations to the north. By January 7, 2001 not only peak $PM_{2.5}$ concentrations in the Northern Valley exceeded Southern and Central Valley peaks, but concentrations above the federal $PM_{2.5}$ standard were also measured in the Sacramento Valley and the San Francisco Bay Area (Figure 10-3).

Figure 10-2 Peak $PM_{2.5}$ concentrations in the San Joaquin Valley between 12/14/99 and 1/1/00.

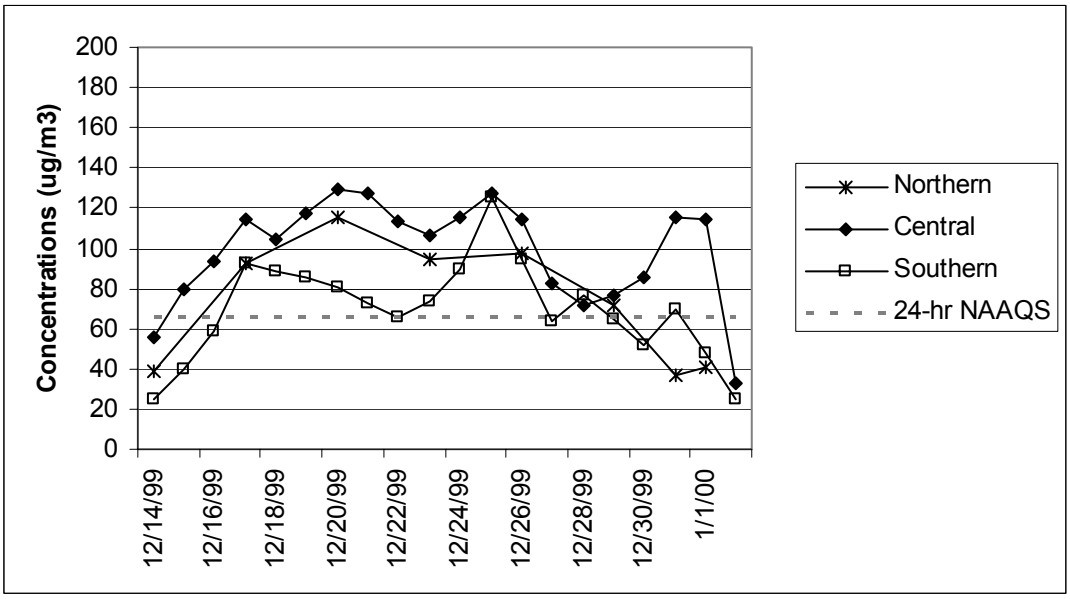
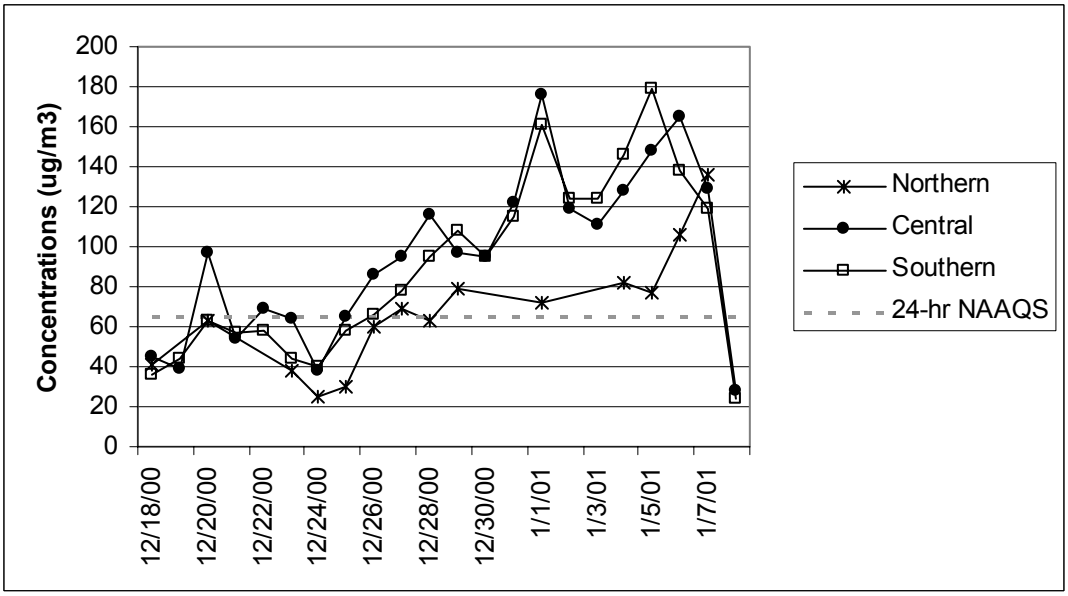


Figure 10-3 Peak $PM_{2.5}$ concentrations in the San Joaquin Valley between 12/18/00 and 1/8/01.



10.4 Chemical Composition

During winter episodes, over 80% of the $PM_{2.5}$ mass in the Central Valley comes from ammonium nitrate and carbonaceous aerosols. The relative proportions between ammonium nitrate and carbonaceous aerosols depend on site characteristics and location. At all rural and most urban sites, ammonium nitrate

concentrations were significantly higher than carbonaceous aerosols. The Fresno area was a notable exception. Rural sites throughout the San Joaquin Valley had $PM_{2.5}$ mass dominated by ammonium nitrate (~60%) with a small carbonaceous aerosols fraction (~20%) (Figure 10-4). Urban chemical composition was more location-dependant with most of the sites, including Bakersfield, exhibiting more ammonium nitrate (~55%) than carbon (~30%). However, the opposite was true for the Fresno area, with ~35% ammonium nitrate and ~50% carbonaceous aerosols.

The December 1999 concentrations were dominated by ammonium nitrate at all sites, including Fresno (Figure 10-5). The December 2000 concentrations, although significantly higher, had a typical winter composition (PM2.5 concentrations were dominated by carbonaceous aerosols at Fresno and by ammonium nitrate at the rest of the Valley sites). Even though the large-scale meteorological conditions (strong inversion, low mixing heights, and light and disorganized winds) were similar during both episodes, some subtle differences may have resulted in different chemical composition. The position of the ridge, further to the north in 1999, may be responsible for greater accumulation of ammonium nitrate over the Fresno area during the first episode. Colder over-night minimum temperatures in the Valley, which led to enhanced wood burning, combined with stronger surface-based inversions may have resulted in higher concentrations of carbonaceous material during the December 2000 episode.

Figure 10-4 Comparison of $PM_{2.5}$ chemical composition on a high $PM_{2.5}$ day at urban and rural locations.

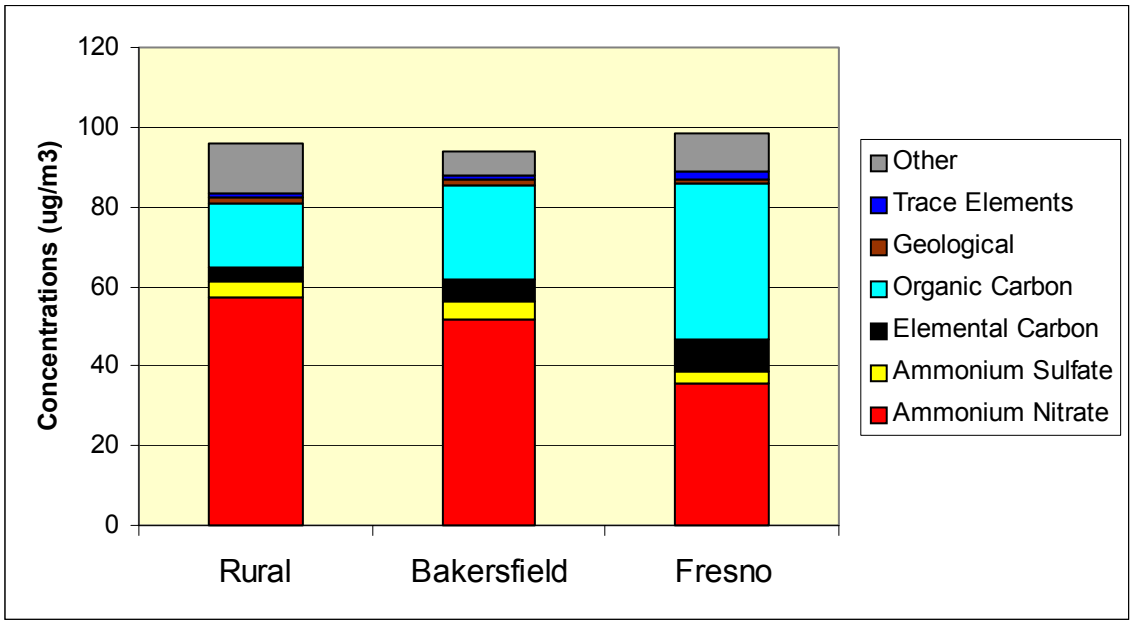
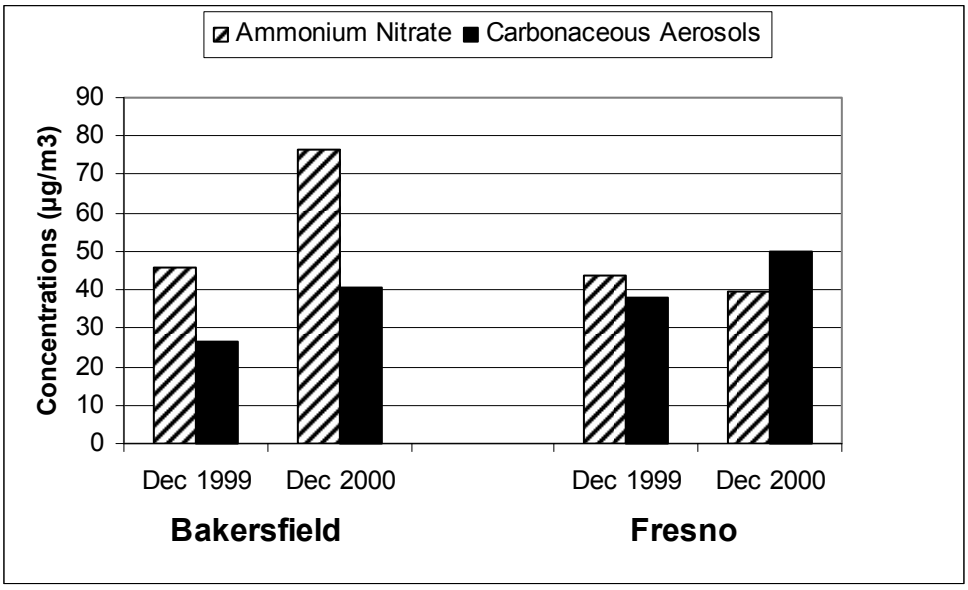


Figure 10-5 Comparison of PM2.5 ammonium nitrate and carbonaceous aerosols concentrations during the December 1999 episode (December 26, 1999) and the December 2000 episode (January 4, 2001) at Bakersfield and Fresno



11 COMPARISON OF URBAN AND RURAL CONCENTRATIONS

During an episode, rural sites followed the same mass buildup but were delayed in time by up to a few days. The duration and intensity of the atmospheric stability (as defined by limited mixing heights and strong inversion) influenced the degree of delay. The stability parameter, defined as the difference between the temperature at the 850mb level and the minimum surface temperature, was used in forecasting high PM concentrations. Weak pressure gradients also contributed to the slow spread of PM and gaseous precursors throughout the Valley. Figure 11-1 shows that the atmosphere was highly stable from the beginning of the December 1999 episode, but then improved after the 7th day.

During the December 1999 episode, rural concentrations build up almost as rapidly as urban. The $PM_{2.5}$ concentrations at Selma, a rural site about 24 km south-southeast of Fresno, were only 20% lower on the 7th day and by the 13th day they exceeded urban concentrations (Figure 11-1). During the December 1999 episode, based on eleven days with matching data, a rural site in Pixley had a peak concentration 6 µg/m^3 higher than an urban site in Bakersfield, but an episode-average concentration 20 µg/m^3 lower and two fewer measured days above the NAAQS.

The December 2000 episode had a longer lag time between urban and rural concentrations (Figure 11-2). It took 18 days for rural concentrations to catch up

with urban. Atmospheric stability decreased early in the episode, but then increased strongly after the first week, accounting for the delay in peak concentrations as well as the lag between urban and rural sites. Although, at the end of the episode, rural sites may have higher concentrations than urban, they still have fewer days above the standard and lower episode-average concentrations due to the lag in the buildup rate.

Figure 11-1 Atmospheric stability and buildup of $PM_{2.5}$ concentrations at an urban and a rural site in the Fresno area during the December 1999 episode.

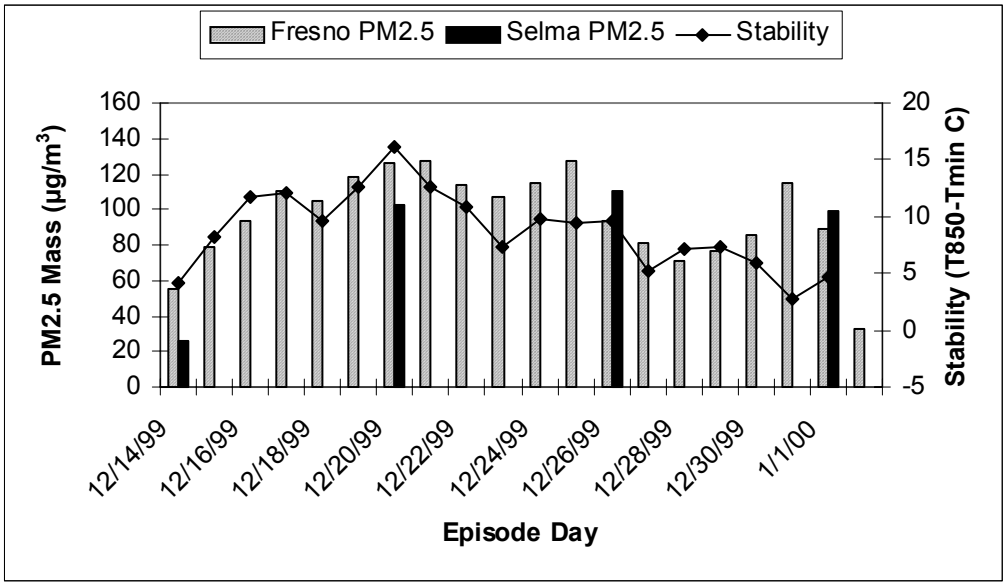
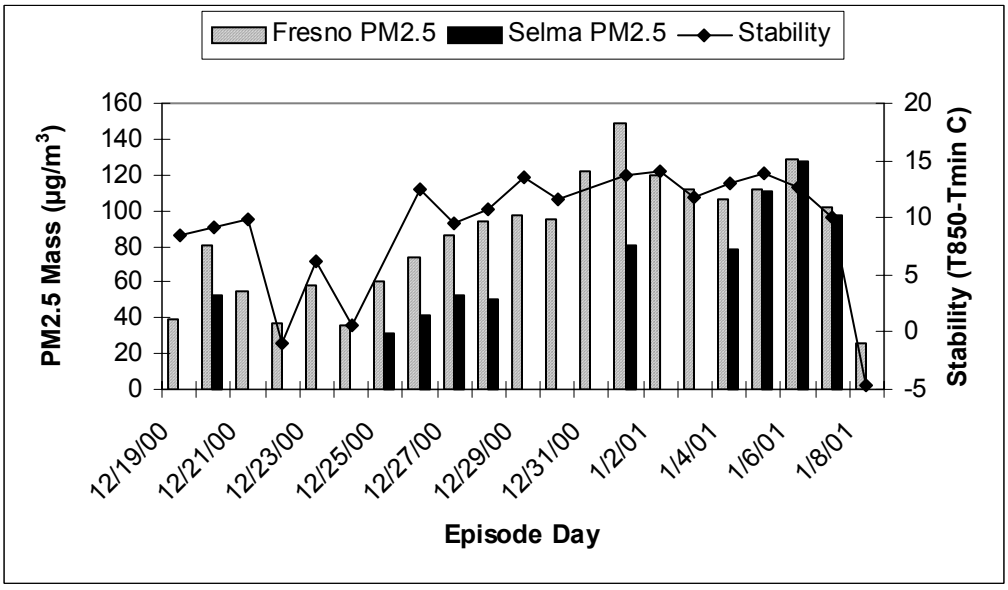


Figure 11-2 Atmospheric stability and buildup of $PM_{2.5}$ concentrations at an urban and a rural site in the Fresno area during the December 2000 episode.



The variations in terrain, emissions, and meteorology throughout the San Joaquin Valley produced two subregions with different PM2.5 concentrations and chemical characteristics. One subregion extended from Stockton in the north to Fresno in the south and the second one encompassed an area south of Fresno, including Bakersfield. Within a subregion, concentrations of ammonium nitrate were relatively uniform, especially toward the end of the episode, but concentrations of carbonaceous aerosols varied significantly from site to site. The most uniform concentrations were measured on December 26, 1999, during the first episode and on January 6, 2001, during the second episode.

During the December 1999 episode, on December 26, 1999, ammonium nitrate concentrations ranged from 40 to 52 $\mu g/m^3$ in the northern subregion and from 42 to 73 $\mu g/m^3$ in the southern subregion. Carbonaceous aerosols ranged from 20 to 46 $\mu g/m^3$ in the northern subregion and from 18 to 32 $\mu g/m^3$ in the southern subregion. The spatial coefficient of ammonium nitrate variation ranged from 10% in the northern subregion to 21% in the southern subregion. Both subregions had similar variation in carbonaceous aerosols of about 25%.

On January 6, 2001, ammonium nitrate concentrations ranged from 45 to 62 $\mu g/m^3$ in the northern subregion and from 72 to 100 $\mu g/m^3$ in the southern subregion. Concentrations of carbonaceous aerosols were 20 to 62 $\mu g/m^3$ and 16 to 37 $\mu g/m^3$, respectively. Similar spatial coefficient of variation of 13% for ammonium nitrate and over 30% for carbonaceous aerosols was found in both subregions.

This difference in spatial distribution between ammonium nitrate and carbonaceous aerosols was related to their origin and formation. Ammonium nitrate is considered a secondary pollutant (formed from directly emitted gases by transformation in the atmosphere). Much of ammonium nitrate is believed to be formed aloft and controlled by nitrogen oxides (NOx) emission rates. Spatial homogeneity of ammonium nitrate is influenced by higher wind speeds aloft (which allow more efficient transport) and diurnal variation in mixing heights (which allow entrainment of ammonium nitrate down to the surface). Stagnant meteorological conditions at the surface allow significant accumulation of not only ammonium nitrate but also primary pollutants (directly emitted into the atmosphere as a particle). Most of the carbonaceous aerosols, including all of EC and over 80% of organics, are considered a primary pollutant. Because they are emitted into the atmosphere as particles, their transport is more limited compared with gaseous ammonium nitrate precursors. Stagnant meteorological conditions hinder it even further, resulting in significant accumulation close to the source. Concentrations of carbonaceous aerosols were two to three times higher at urban sites than at rural because of the greater number of primary emission sources in the urban areas.

Figure 11-3 Spatial variation of PM2.5 ammonium nitrate and carbonaceous aerosols on December 26, 1999, during the December 1999 episode.

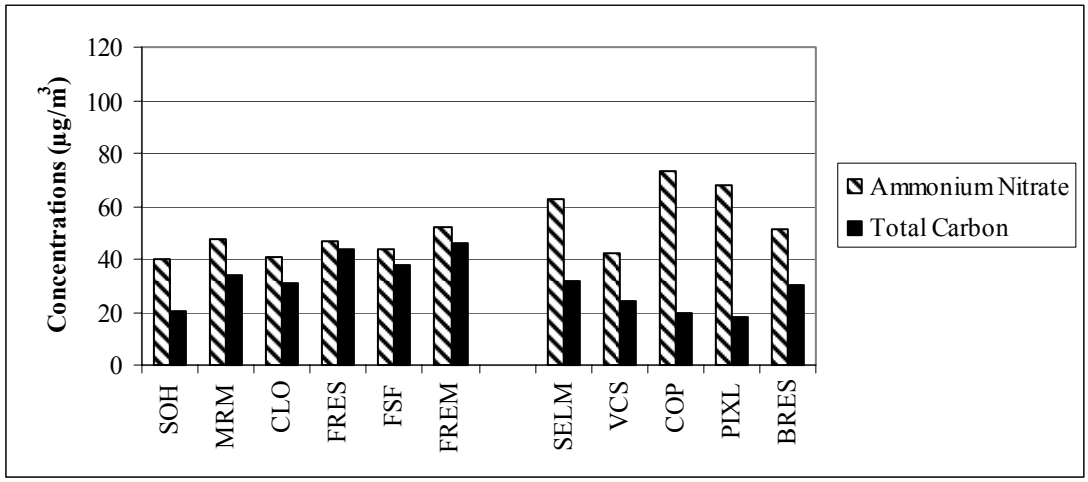
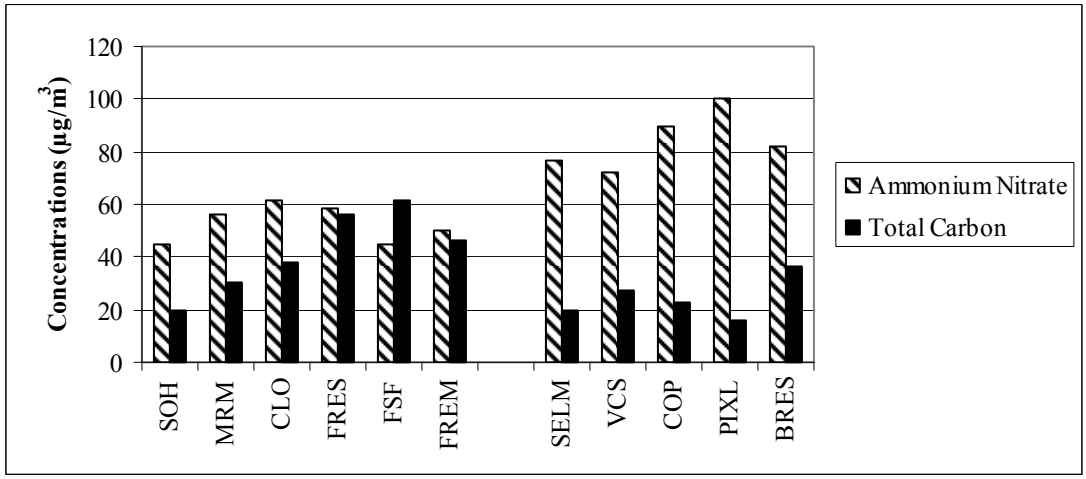


Figure 11-4 Spatial variation of PM2.5 ammonium nitrate and carbonaceous aerosols on January 6, 2001, during the December 2000 episode.



Appendix A
Particulate Matter Monitoring Sites in the
San Joaquin Valley, Sacramento Valley, and San Francisco Bay Area Air Basins.

Basin	Site Name	Site ID
SJV	Agricultural fields/Helm-Central Fresno County	HELM
SJV	ANGIOLA	ANGI
SJV	BAC Residential	BRES
SJV	Bakersfield-410 E Planz Road	BSE
SJV	Bakersfield-5558 California Avenue	BAC
SJV	Bakersfield-Golden State Highway	BGS
SJV	Clovis-N Villa Avenue	CLO
SJV	Corcoran-Patterson Avenue	COP
SJV	Edison	EDI
SJV	Feedlot or Dairy	FEDL
SJV	Fellows	FEL
SJV	Foothills above Fellows	FELF
SJV	Fresno MV	FREM
SJV	Fresno-1st Street	FSF
SJV	Fresno-Hamilton & Winery	FSE
SJV	Kettleman City	KCW
SJV	Merced-2334 M Street	MRM
SJV	Modesto-14th Street	M14
SJV	Oildale-3311 Manor Street	OLD
SJV	Pacheco Pass	PAC1
SJV	Pixley Wildlife Refuge	PIXL
SJV	Residential area near FRS, with woodburning	FRES
SJV	Selma(south Fresno area gradient site)	SELM
SJV	Sierra Nevada Foothills	SNFH
SJV	Stockton-Hazelton Street	SOH
SJV	SW Chowchilla	SWC
SJV	Taft College	TAC
SJV	Tehachapi Pass	TEH2
SJV	Visalia-N Church Street	VCS

Basin	Site Name	Site ID
SV	Chico-Manzanita Avenue	CHM
SV	Colusa-Sunrise Blvd	CSS
SV	Pleasant Grove (north of Sacramento)	PLE
SV	Redding-Health Dept Roof	RDG
SV	Roseville-N Sunrise Blvd	ROS
SV	Sacramento-Del Paso Manor	SDP
SV	Sacramento-Health Dept Stockton Blvd	SST
SV	Sacramento-T Street	S13
SV	Woodland-Gibson Road	WLN
SV	Yuba City-Almond Street	YAS
SFB	Altamont Pass	ALT1
SFB	Bethel Island	BTI
SFB	Bodega Marine Lab	BODG
SFB	Concord-2975 Treat Blvd	CCD
SFB	Fremont-Chapel Way	FCW
SFB	Livermore-793 Rincon Avenue	LVR1
SFB	Redwood City	RED
SFB	San Francisco-Arkansas Street	SFA
SFB	San Jose-4th Street	SJ4
SFB	San Jose-Tully Road	SJT
SFB	Santa Rosa-5th Street	SRF
SFB	Vallejo-304 Tuolumne Street	VJO